Solutions Manual

ENGINEERING ELECTRONICS

Harry E. Stewart

Allyn and Bacon, Inc.
Boston

Solutions Manual
to accompany

ENGINEERING ELECTRONICS

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ALLYN AND BACON, INC.
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Solutions Manual

CHAPTER 1

1.1 $r = \dfrac{\epsilon_0 h^2 n^2}{Z e^2 m \pi} = 5.3 \times 10^{-11}\ m = 0.53\ \text{Å}$ (for $n=1$)

1.2 energy radiated $= U_3 - U_2 = -1.51 - (-3.39)$
" " $= 1.88$ ev

$$f = \frac{U}{h} = \frac{1.88 \times 1.6 \times 10^{-19}}{6.625 \times 10^{-34}} = 0.454 \times 10^{15}\ Hz$$

$$U = -3.39 - (-13.56) = 10.17\ ev$$

$$f = \frac{10.17 \times 1.60 \times 10^{-19}}{6.625 \times 10^{-34}} = 2.45 \times 10^{15}\ Hz$$

1.3 Eq (1.26) which applies only to simplest case of a single electron in the vicinity of the nucleus, shows that the energy U varies inversely as the square of the principal quantum number n. C, Si, and Ge have their valence electrons in the following outer shells and energy states:

C: $n = 2$ and $2s^2 2p^2$

Si: $n = 3$ and $3s^2 3p^2$

Ge: $n = 4$ and $4s^2 4p^2$

Using Eq (1.26), we compute the

following values for Eg:

$$E_g(\text{carbon}) = 1.20\left[\frac{\frac{1}{2^2}-\frac{1}{3^2}}{\frac{1}{3^2}-\frac{1}{4^2}}\right] = 3.44\ ev$$

$$E_g(\text{Germonium}) = 1.20\left[\frac{\frac{1}{4^2}-\frac{1}{5^2}}{\frac{1}{3^2}-\frac{1}{4^2}}\right] = 0.555\ ev$$

THESE VALUES are lower than the actual values.

1.4 $$\text{ATOMS/CC} = \frac{(\text{DENSITY})(\text{AVOGADRO'S NUMBER})}{\text{ATOMIC WEIGHT}}$$

Ge: 4.42×10^{22} ATOMS/CC

Si: 4.99×10^{22} " / "

As: 4.60×10^{22} " / "

In: 3.81×10^{22} " / "

1.5 Ge: 8.29×10^{21} ATOMS/gm

Si: 21.42×10^{21} " / "

As: 8.03×10^{21} " / "

In: 5.24×10^{21} " / "

1.6 $hf = eE_g = \dfrac{hc}{\lambda}$

$$\lambda = \frac{hc}{eE_g} = \frac{6.625 \times 10^{-34} \times 300 \times 10^{6}}{1.60 \times 10^{-19} \times 0.78}$$

$$\lambda = 15.9 \times 10^{-7}\ m = 15{,}900\ \mathring{A}$$

visible spectrum: $4000 - 7000\ \mathring{A}$

1.7 Results given in text on page 29.

1.8 $\sigma = 1.05 \times 10^{3}\, T^{3/2} \exp(-7000/T)$

$$\sigma = 1.05 \times 10^{3} (350^{\circ}) \exp(-7000/350)$$

$$\sigma = 1.05 \times 10^{3} \times 6550 \times 20.25 \times 10^{-10} = 13.92 \times 10^{-3}\ (\Omega\text{-}m)^{-1}$$

$$\frac{\sigma(350^{\circ})}{\sigma(300^{\circ})} = \frac{13.92 \times 10^{-3}}{0.422 \times 10^{-3}} = 33$$

Conductivity increases by factor of 33.

1.9 $\sigma = (n\mu_n + p\mu_p)e = n_i e(\mu_n + \mu_p)$

$$\sigma = 2 \times 10^{13} \times 1.60 \times 10^{-19} (2000 + 1000) = 9.6 \times 10^{-3}$$

$$\rho = \frac{1}{\sigma} = \frac{1}{9.6 \times 10^{-3}} = 104.3\ \text{ohm-cm}$$

$$R = \frac{\rho l}{A} = \frac{104.3 \times 10}{\frac{\pi}{4}(1)^2} = 132.50\ \Omega$$

1.10 $I = neAv_a$

$$v_a = \frac{I}{neA} = \frac{1.0}{6.05\times10^{22}\times1.60\times10^{-19}\ A}$$

$$A = \frac{\pi}{4}d^2 = \frac{\pi}{4}(0.032''\times2.54)^2 = 5.18\times10^{-3}\ cm^2$$

$$v_a = 0.020\ cm/sec.$$

$$\rho = \frac{RA}{l} = \frac{16.70\times5.18\times10^{-3}}{1000'\times12''\times2.54} = 2.84\times10^{-7}\ \Omega\text{-cm}$$

$$\mu = \frac{\sigma}{ne} = \frac{1}{\rho ne} = \frac{1}{2.84\times10^{-7}\times6.05\times10^{22}\times1.60\times10^{-19}}$$

$$\mu = 36.4\ cm^2/v\text{-}s$$

CHAPTER 2

2.1 Using the results of Problem 1.5, we have

No. of atoms in 100 gms Ge $= 8.29\times10^{23}$

No. of atoms of As required $= \dfrac{8.29\times10^{23}}{10^8} = 8.29\times10^{15}$

No. of gms of As required $= \dfrac{8.29\times10^{15}}{8.03\times10^{21}} = 1.035\times10^{-6}$

No. of As atoms/cm³ $= \dfrac{4.42\times10^{22}}{10^8} = 4.42\times10^{14}$

$$p = \frac{n_i^2}{N_d} = \frac{(2.4\times10^{13})^2}{4.42\times10^{14}} = 1.30\times10^{12}\ holes/cm^3$$

$$n = N_d + p = (4.42 + 0.0130)10^{14} = 4.42\times10^{14}$$

2.1 (cont.)

$$\sigma = e(n\mu_n + p\mu_p) \doteq en\mu_n \doteq eN_d\mu_n$$

$$\sigma = 1.60 \times 10^{-19} \times 4.42 \times 10^{14} \times 3900 = 276 \times 10^{-3} (\mho\text{-cm})^{-1}$$

2.2 1×10^{-6} gms of As has 8.03×10^{15} atoms

2×10^{-6} gms of In has 10.48×10^{15} atoms

$$\text{Vol. of 100 gms Ge} = \frac{100}{5.33} = 18.75 \text{ cm}^3$$

$$N_d = \frac{8.03 \times 10^{15}}{18.75} = 4.28 \times 10^{14} \text{ electrons/cm}^3$$

$$N_a = \frac{10.48 \times 10^{15}}{18.75} = 5.6 \times 10^{14} \text{ holes/cm}^3$$

$$N_a - N_d = 1.32 \times 10^{14} \text{ holes/cm}^3$$

$$n = \frac{n_i^2}{N_a - N_d} = \frac{(2.40 \times 10^{13})^2}{1.32 \times 10^{14}} = 4.36 \times 10^{12}$$

$$\sigma = e(n\mu_n + p\mu_p) = e(4.36 \times 10^{12} \times 3900 + 1.32 \times 10^{14} \times 1900)$$

$$\sigma = 1.60 \times 10^{-19} \times 267 \times 10^{15} = 0.0428 \ (\mho\text{-cm})^{-1}$$

2.3 1×10^{-6} gms As has 8.03×10^{15} atoms

$$\text{No. gms of In} = \frac{8.03 \times 10^{15} \times 114.82}{6.02 \times 10^{23}}$$

$$\text{" \quad " \quad " \quad "} = 1.535 \times 10^{-6}$$

2.4 Taking the derivative of Eq (2.27) with respect to the temperature T, we get

$$\frac{dI_s}{dT} = \frac{I_s}{T}\left(3 + \frac{E_g}{kT}\right)$$

For Silicon at 300°K:

$$\frac{dI_s}{dT} = \frac{I_s}{300}\left(3 + \frac{14{,}000}{300}\right) = \frac{I_s}{6} = 0.167\, I_s$$

For Germanium at 300°K:

$$\frac{dI_s}{dT} = \frac{I_s}{300}\left(3 + \frac{9100}{300}\right) = 0.11\, I_s$$

2.5 Substituting the values given into Eq (2.60), we get

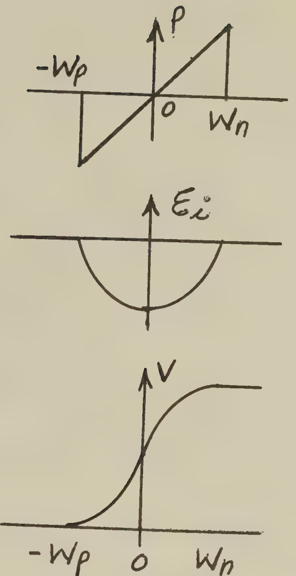
$$\mathcal{E}_i(max) \doteq \left[\frac{-2\sigma_n V_J}{\epsilon \mu_n}\right]^{1/2} = \left[\frac{-2\sigma_n V_J}{1.40 \times 10^{-10} \times 0.39}\right]^{1/2}$$

$$\mathcal{E}_i(max) = 1.91 \times 10^5 \left[-\sigma_n V_J\right]^{1/2} = 1.91 \times 10^5 \left[100\right]^{1/2}$$

$$\mathcal{E}_i(max) = 1.91 \times 10^6 \text{ V/m} = 19{,}100 \text{ V/cm}.$$

2.6 Referring to Fig P2.6 and following the procedure outlined in pages 60-63, we can derive the expressions for $\mathcal{E}_i$, V, W_B, and C_j.

2.6 (Cont.)



$$\rho = ax, \quad a = \frac{e(N_a+N_d)}{W}$$

$$\frac{d^2V}{dx^2} = \frac{-\rho}{\epsilon} = -\frac{ax}{\epsilon}$$

$$\frac{dV}{dx} = \frac{-ax^2}{2\epsilon} + C_1$$

At $x = -W_p$, $\frac{dV}{dx} = -\mathcal{E}_i = 0$

$$C_1 = \frac{aW_p^2}{2\epsilon}$$

$$\frac{dV}{dx} = -\mathcal{E}_i = \frac{a}{2\epsilon}(W_p^2 - x^2)$$

$$V = \frac{a}{2\epsilon}\left(W_p^2 x - \frac{x^3}{3}\right) + C_2 \; ; \quad \text{At } x = -W_p, \quad V = 0$$

$$V = \frac{a}{2\epsilon}\left(W_p^2 x - \frac{x^3}{3} + \frac{2W_p^3}{3}\right); \qquad C_2 = \frac{aW_p^3}{3\epsilon}$$

At $x = 0$, $V = V_p = \dfrac{aW_p^3}{3\epsilon}$

In a similiar manner, $V_n = \dfrac{aW_n^3}{3\epsilon}$

$$V_B = V_p + V_n = \frac{a}{3\epsilon}(W_p^3 + W_n^3)$$

Because of symmetry: $V_B = 2V_p = 2V_n$

$W_B = 2W_p = 2W_n$

2.6 (Concl.)

$$V_B = \frac{aW_B^3}{12\epsilon} \quad \text{and} \quad W_B = \left[\frac{12\epsilon V_B}{a}\right]^{1/3}$$

$$C_j = \frac{dQ}{dV_B} \quad \text{where } dQ = aW_p\,dW_p = \frac{aW_B\,dW_B}{4}$$

$$dV_B = \frac{3aW_B^2\,dW_B}{12\epsilon} = \frac{aW_B^2\,dW_B}{4}$$

$$C_j = \frac{\epsilon}{W_B} = \epsilon^{2/3}\left[\frac{a}{12V_B}\right]^{1/3}$$

2.7

$$n_{po} = \frac{n_i^2}{N_a} = \frac{(2.4\times10^{19})^2}{10\times10^{20}} = 5.76\times10^{17} \text{ electrons/m}^3$$

$$p_{no} = \frac{n_i^2}{N_d} = \frac{(2.4\times10^{19})^2}{10\times10^{19}} = 5.76\times10^{18} \text{ holes/m}^3$$

$$\exp(-eV_d/kT) = \frac{n_{po}}{n_n} = \frac{5.76\times10^{17}}{10\times10^{19}} = 5.76\times10^{-3}$$

$$\frac{-V_D}{0.026} = -5.15 \quad \text{and} \quad V_D = 0.134 \text{ volts}$$

From Eq (2.45), $W_n = (15.9\times10^{-12}V_B)^{1/2}$

$$\text{''} = (15.9\times10^{-12}\times0.134)$$

$$\text{''} = 1.46\times10^{-6} \text{ m}$$

$$W_p = \frac{N_d W_n}{N_a} = \frac{10^{20}W_n}{10^{21}} = 0.10\,W_n = 1.46\times10^{-7} \text{ m}$$

2.7 (Concl.)

$$\mathcal{E}_i(max) = \frac{eN_d W_n}{\epsilon} = \frac{1.60\times10^{-19}\times10^{20}\times1.46\times10^{-6}}{15.8\times8.85\times10^{-12}}$$

$$= 1.67\times10^{5} \text{ volts/m}$$

Plots of charge densities, field intensity, and carrier concentrations are not included here because they are quite similiar to the plots given in Fig 2.4.

2.8

$$n_p(0) = n_{po}\exp(eV_J/kT) = 5.76\times10^{17}\exp\left(\frac{0.10}{0.026}\right)$$

$$= 5.76\times10^{17}\times 47.5 = 274\times10^{17} \text{ electrons/m}^3$$

$$p_n(0) = p_{no}\exp(eV_J/kT) = 5.76\times10^{18}\exp\left(\frac{0.10}{0.026}\right)$$

$$= 5.76\times10^{18}\times 47.5 = 274\times10^{18} \text{ holes/m}^3$$

$$W_n = [15.9\times10^{-12} V_B]^{1/2} = [15.9\times10^{-12}(V_0 - V_J)]^{1/2}$$

$$= [15.9\times10^{-12}(0.134 - 0.10)]^{1/2} = 0.734\times10^{-6} \text{ m}$$

$$W_p = 0.10\times 0.734\times10^{-6} \text{ m} = 0.734\times10^{-7} \text{ m}$$

$$\mathcal{E}_i(max) = \frac{1.60\times10^{-19}\times10^{20}\times0.734\times10^{-6}}{1.40\times10^{-10}}$$

$$= 0.839\times10^{5} \text{ volts/m}$$

Plots are similiar to those shown in Fig 2.5.

2.9

$$n_p(0) = 5.76\times10^{17}\exp\left(\frac{-10}{.026}\right) = 5.76\times10^{17}\exp(-385)$$

$$= 5.76\times10^{17}\times 4.35\times10^{-11} = 25\times10^{6} \text{ electrons}/m^3$$

$$p_n(0) = 5.76\times10^{18}\times 4.35\times10^{-11} = 25\times10^{7} \text{ holes}/m^3$$

$$W_n = [15.9\times10^{-12}(0.134+10)]^{1/2} = 12.68\times10^{-6}\ m$$

$$W_p = 0.10\times12.68\times10^{-6} = 12.68\times10^{-7}\ m$$

$$\mathcal{E}_i(max) = \frac{1.60\times10^{-19}\times10^{20}\times12.68\times10^{-6}}{1.40\times10^{-10}}$$

$$= 14.5\times10^{5} \text{ volts}/m$$

Plots are similiar to those shown in Fig 2.6.

2.10

Rearranging Eq (2.60), we have

$$\sigma_n = \frac{-\mathcal{E}_i^2\,\epsilon\,\mu_n}{2V_J} = \frac{-400\times10^{12}\times1.40\times10^{-10}\times0.39}{2(-10)}$$

$$\sigma_n = 1.09\times10^{3}\quad(\Omega\text{-}m)^{-1}$$

2.11

(a) $$n_i = 3.87\times10^{22}(400)^{3/2}\exp\left(-\frac{7000}{400}\right)$$

$$= 3.10\times10^{26}\exp(-17.5) = 3.10\times10^{26}\times2.43\times10^{-8}$$

$$= 7.53\times10^{18}$$

2.11 (Concl.)

$$p = -\frac{N_d}{2} + \frac{N_d}{2}\left[1 + \left(\frac{2n_i}{N_d}\right)^2\right]^{1/2}$$

$$p = -\frac{N_d}{2} + \frac{N_d}{2}\left[1 + \left(\frac{2\times 7.53\times 10^{18}}{1\times 10^{17}}\right)^2\right]^{1/2}$$

$$= -\frac{N_d}{2} + \frac{N_d}{2}[150.6] \doteq \frac{N_d}{2}(150.6) = \frac{1\times 10^{17}\times 150.6}{2}$$

$$= 7.53\times 10^{18} \text{ holes}/m^3$$

$$n = N_d + p = 1\times 10^{17} + 7.53\times 10^{18} = 7.63\times 10^{18} \text{ elec}/m^3$$

$N_d \ll n$ so doping is light at 400°K.

(b)

$$\sigma = e(n\mu_n + p\mu_p)$$

$$= 1.60\times 10^{-19}(7.63\times 10^{18}\times 0.12 + 7.53\times 10^{18}\times 0.05)$$

$$= 0.207\ (\Omega\text{-}m)^{-1}$$

(c) intrinsic Si at 400°K has σ of

$$\sigma = 1.05\times 10^{3}(400)^{3/2}\exp(-7000/400)$$

$$= 1.05\times 10^{3}\times 8\times 10^{3}\exp(-17.5) = 0.204\ (\Omega\text{-}m)^{-1}$$

Conductivity of intrinsic and doped Si at 400°K are essentially the same. Material, therefore, behaves as lightly (almost intrinsic) doped material.

2.12

(a) $E_i = R_s I_i + V_z = R_s(I_z + I_L) + V_z$

$$R_s = \frac{E_i - V_z}{I_z + I_L} \quad \text{and} \quad I_z = \frac{E_i - V_z}{R_s} - I_L$$

(b) For Constant $E_L = V_z$, $I_i = I_z + I_L =$ constant

For $I_L = 0$, $I_z = 100$ ma, $I_i = 100$ ma

$$R_s = \frac{10-6}{0.100} = 40\,\Omega$$

For $I_z = 5$ ma, $I_L = 100 - 5 = 95$ ma

(c) For $E_i = 11$ volts, $I_i = \frac{11-6}{40} = 125$ ma

$I_L(min) = 125 - 100 = 25$ ma

$I_L(max) = 125 - 5 = 120$ ma

CHAPTER 3

3.1 For Caesium: $\phi_W = 1.81$ ev; $f = 6 \times 10^{14}$ Hz

(a) $KE = hf - e\phi_W = 6.63 \times 10^{-34} f - 2.90 \times 10^{-19}$

$KE = (3.98 - 2.90)10^{-19} = 1.08 \times 10^{-19}$ Joules

$KE = 0.675$ ev

$$v_e = \left[\frac{2\,KE}{m}\right]^{1/2} = \left[\frac{2 \times 1.08 \times 10^{-19}}{9.11 \times 10^{-31}}\right]$$

$v_e = 0.486 \times 10^6$ m/s

3.1 (Concl.)

(b) Reverse bias required = −0.68 volts

3.2

(a) $J = 60 \times 10^4 (2500)^2 \exp(-52{,}400/2500)$

$$= 60 \times 10^4 \times 6.25 \times 10^6 \times 8.21 \times 10^{-10} = 30.8 \times 10^2 \text{ amps/m}^2$$

$$\text{AREA FOR 100 ma} = \frac{0.100}{0.308} = 0.325 \text{ cm}^2$$

(b) $J = 0.10 \times 10^4 (1000)^2 \exp(-11{,}600/1000)$

$$= 0.10 \times 10^4 \times 10^6 \times 9.10 \times 10^{-6} = 9.10 \times 10^2 \text{ amps/m}^2$$

$$\text{Area for 100 ma} = \frac{0.100}{0.091} = 1.10 \text{ cm}^2$$

3.3 From Eq (3.20), we have

$$\frac{e_b^{3/2}}{d^2} = \frac{\phi^{3/2}}{x^2} \quad \text{and} \quad \phi = \frac{e_b x^{4/3}}{d^{4/3}}$$

$$\mathcal{E} = -\frac{d\phi}{dx} = \frac{4}{3} \frac{e_b x^{1/3}}{d^{4/3}}$$

$$\frac{m_e v^2}{2} = e\phi \quad \text{and} \quad v = \left[\frac{2 e e_b x^{4/3}}{m_e d^{4/3}}\right]^{1/2}$$

$$\rho = -\frac{J_b}{v} = \frac{-4\epsilon_0}{9}\left(\frac{2e}{m}\right)^{1/2}\left[\frac{m d^{4/3}}{2e\, e_b x^{4/3}}\right]^{1/2} \frac{e_b^{3/2}}{d^2}$$

$$\rho = \frac{4\epsilon_0 e_b}{9 d^{4/3} x^{2/3}}$$

3.4 LET DIODE CURRENT $= I_b$

(a) $I_b + I_L = \text{constant}$

FOR $I_L = 0$, $I_b(max) = 40$ ma

$\therefore I_b + I_L = 40$ ma

$I_L(max) = 40 - 5 = 35$ ma

$$R_S = \frac{E_1 - E_L}{I_b + I_L} = \frac{200-150}{40} = 1.25\ k\Omega$$

(b)

$$R_L(min) = \frac{E_L}{I_L(max)} = \frac{150}{35} = 4.28\ k\Omega$$

DIODE VOLTAGE $V_b = \dfrac{200 \times 4.28}{1.25+4.28} = 155$ volts

Ignition voltage $V_b = 160$ (Table 3.2)

$$E_1(min) = \frac{(1.25+4.28)\,160}{4.28} = 206 \text{ volts}$$

3.5

(a) $a = \dfrac{dv}{dt} = \dfrac{d^2x}{dt^2}$ and $f = ma = e\mathcal{E}$

$$a = \frac{e\mathcal{E}}{m} = \frac{e}{m}\cdot\frac{4}{3}\,\frac{E_b\,x^{1/3}}{d^{4/3}} = k\,x^{1/3}$$

$$k = \frac{4eE_b}{3md^{4/3}}$$

$$a = \frac{dv}{dt} = \frac{d^2x}{dt^2}$$

Now $\dfrac{d(v^2)}{dt} = 2\dfrac{dv}{dt}$

3.5 (Concl.)

So $\frac{d\left(\frac{dx}{dt}\right)^2}{dt} = 2\frac{dx}{dt}\frac{d^2x}{dt^2} = 2a\frac{dx}{dt} = 2kx^{1/3}\frac{dx}{dt}$

Integrating, we get

$$v^2 = \left(\frac{dx}{dt}\right)^2 = \frac{2kx^{4/3}}{4/3} + C_1 \quad \left(\begin{matrix}C_1 = 0 \text{ because} \\ v = 0 \text{ at } x = 0\end{matrix}\right)$$

$$v = \frac{dx}{dt} = \left[\frac{3kx^{4/3}}{2}\right]^{1/2} = \left[\frac{2eE_b x^{4/3}}{m\, d^{4/3}}\right]^{1/2}$$

Rearranging and integrating again, we obtain

$$x^{-2/3}dx = \left(\frac{3k}{2}\right)^{1/2}$$

$$3x^{1/3} = \left(\frac{3k}{2}\right)^{1/2} t + C_2 \quad \left(\begin{matrix}C_2 = 0 \text{ because} \\ x = 0 \text{ at } t = 0\end{matrix}\right)$$

$$t = \frac{3x^{1/3}}{(1.5k)^{1/2}}$$

$$\text{Transit time} = T = \frac{3d^{1/3}}{(1.5k)^{1/2}} = 1.5d\left(\frac{2m}{eE_b}\right)^{1/2}$$

$$T = 1.5\times10^{-2}\left(\frac{2}{1.76\times10^{11}\times100}\right)^{1/2} = 5.05\times10^{-9}\text{ sec}$$

(b)

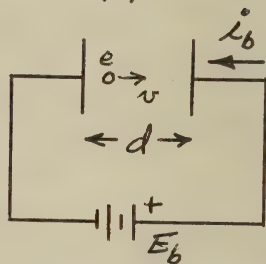
$$\text{Terminal velocity} = v_T = \left[\frac{2eE_b}{m}\right]^{1/2}$$

$$v_T = [2\times1.76\times10^{11}\times100]^{1/2} = 5.93\times10^{6}\text{ m/s}$$

3.6

(a) $f = ma = e\mathcal{E}$ and $a = \dfrac{e\mathcal{E}}{m}$

$$\mathcal{E} = \frac{E_b}{d}$$



$$dx = v\,dt = a\,t\,dt$$

$$x = \frac{at^2}{2}$$

$$t = \left[\frac{2xm}{e\mathcal{E}}\right]^{1/2} = \left[\frac{2xmd}{eE_b}\right]^{1/2}$$ charge-free region

$$\text{Transit time} = T = d\left[\frac{2m}{eE_b}\right]^{1/2}$$

$$T = 1\times10^{-2}\left[\frac{2}{1.76\times10^{11}\times100}\right]^{1/2} = 3.37\times10^{-9}\ \text{sec}$$

(b) $\text{Work} = W = fx = e\mathcal{E}x = \dfrac{exE_b}{d}$

$$\text{Power} = p = \frac{dW}{dt} = \frac{eE_b}{d}\frac{dx}{dt} = \frac{eE_b}{d}v$$

$$p = E_b i_b = \frac{eE_b}{d}v$$

$$i_b(t) = \frac{ev}{d} = \frac{eat}{d} = \frac{e}{d}\left(\frac{e}{m}\right)\frac{E_b}{d}t$$

$$i_b(t) = \frac{1.6\times10^{-19}\times1.76\times10^{11}\times100\,t}{1\times10^{-4}} = 2.82\times10^{-2}\,t\ \text{amps.}$$

3.7 From Prob 3.3

(a) $v = v_0 + \left[\frac{2e\,E_b\,x^{4/3}}{m\,d^{4/3}}\right]^{1/2}$

$v = 1\times10^6 + \left[\frac{2\times1.76\times10^{11}\times100}{1}\right]^{1/2} = 6.93\times10^6\ m/s$

initial $KE = \frac{1}{2}m v_0^2 = e\phi_0$

$\phi_0 = \frac{m v_0^2}{2e} = \frac{(1\times10^6)^2}{2\times1.76\times10^{11}} = 2.84$ volts

Total $KE = \phi_0 + E_b = 2.84 + 100 = 102.84$ ev

(b) ANODE DISSIPATION $= (\phi_0 + E_b)\,I_b = 102.84\times0.010$
$= 1.0284$ watts

Power is not useful; it raises the temperature of the anode.

(c) $i_b = k\,e_b^{3/2}$ and $10 = k(100)^{3/2} = 1000\,k$

$k = \frac{10}{1000} = 0.01$ and $i_b(ma) = 0.010\,e_b^{3/2}$

3.8 (a) $J = AT^2\epsilon^{-b_0/T} = 0.01\times10^4(1000)^2\epsilon^{-11{,}600/1000}$
$= 0.010\times10^{10}\epsilon^{-11.6} = 0.09\times10^4\ a/m^2$
$= 0.09\ amps/cm^2$

(b) Area $= \frac{100}{90} = 1.10\ cm^2$

(c) Heater power $= W_H = \frac{100}{200} = 0.50$ watts

Heater current $= I_H = \frac{0.50}{6.3} = 0.0795$ amp

CHAPTER 4

4.1 $i_b = k\, e_b^{3/2} = 0.25\, e_b^{3/2}$ ma

Correction: Top terminal of E in Fig P4.1 should be positive.

$$E - R i_b = e_b = \left(\frac{i_b}{k}\right)^{2/3}$$

$$(E - R i_b)^3 = \left(\frac{i_b}{k}\right)^2$$

Substituting numerical values, we get the following cubic equation:

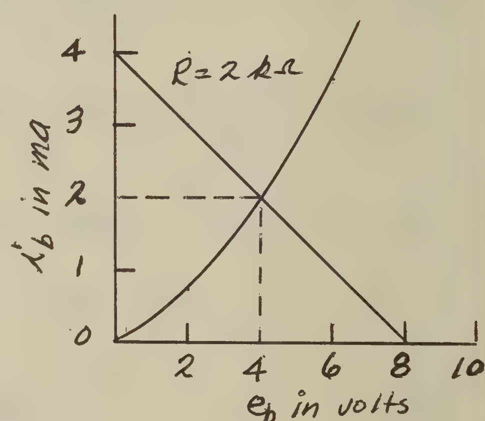
$$i_b^3 - 10 i_b^2 + 48 i_b - 64 = 0$$

$$(i_b - 2)(i_b^2 - 8 i_b + 32) = (i_b - 2)(i_b - 4 - j4)(i_b - 4 + j4) = 0$$

(b) Graphical solution yields a value of

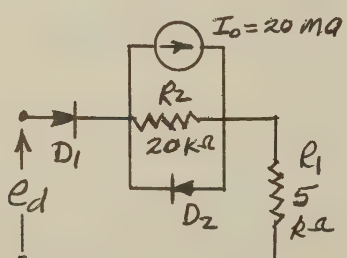
$i_b = 2$ ma

which agrees with value determined in (a).

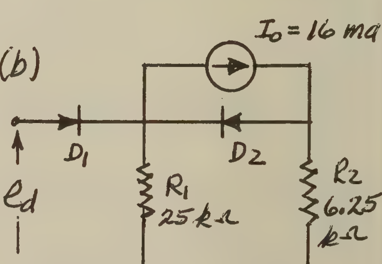


4.2

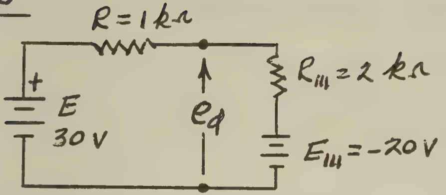
(a)



(b)



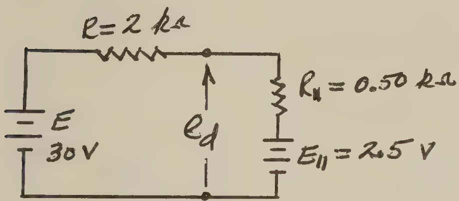
4.3



$$i = \frac{E - E_{III}}{R + R_{III}}$$

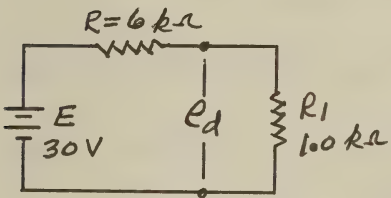
$$i = \frac{30-(-20)}{1+2} = 16.67 \text{ ma}$$

$e_R = 16.67$ volts
$e_d = 13.33$ "



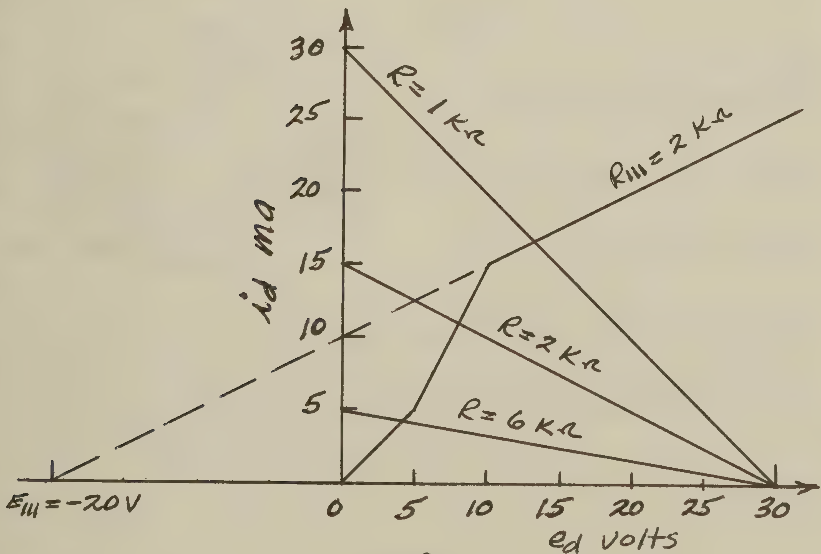
$$i = \frac{30-2.5}{2.5} = 11 \text{ ma}$$

$e_R = 22$ V
$e_d = 8$ V



$$i = \frac{30}{7} = 4.28 \text{ ma}$$

$e_R = 25.68$ V
$e_d = 4.32$ V



4.4 $e_x = E_{III} + [e_x(0) - E_{III}]\,exp(-t/\tau_{III})$

$e_x = -20 + [30-(-20)]\,exp(-t/2\,ms)$

$10 = -20 + 50\,exp(\delta_{III}/2\,ms)$

$\delta_{III} = 0.50\,\tau_{III} = 1.02\,ms$

$e_x = E_{II} + [10 - E_{II}]\,exp(-t/\tau_{II})$

$5 = 2.5 + 7.5\,exp(-\delta_{II}/0.50)$

$\delta_{II} = 1.1\,\tau_{II} = 0.55\,ms$

$e_x = 5\,exp(-t/\tau_I) = 5\,exp(-t/1)$

$3 = 5\,exp(-\delta_I/1)$ and $\delta_I = 0.5\,\tau_I = 0.50\,ms$

TOTAL TIME $= \delta_T = \delta_I + \delta_{II} + \delta_{III} = 0.50 + 0.55 + 1.02$

$= 2.17\,ms$

4.5

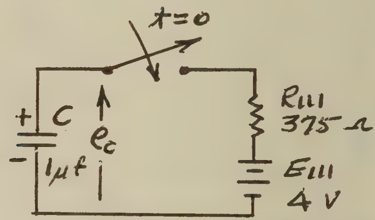
$e_c(0^+) = 16\,V$

$e_c(t) = E_{III} - [E_{III} - e_c(0^+)]\,\epsilon^{-t/\tau_{III}}$

$e_c(t) = 4 + 12\,\epsilon^{-t/\tau_{III}}$

$7 = 4 + 12\,\epsilon^{-\delta/0.375}$

$\delta = 1.39\,\tau_{III} = 0.521\,ms$



$\tau_{III} = 0.375\,ms$

$\underline{4.6}$ $\quad i_b = k e_b^2$ and $i_c = C \dfrac{de_b}{dt}$

$$i_b + i_c = k e_b^2 + C \frac{de_b}{dt} = 0$$

$$e_b = \frac{1}{\frac{kt}{C} + K_1}$$

at $t = 0$, $e_b(0) = E_a$

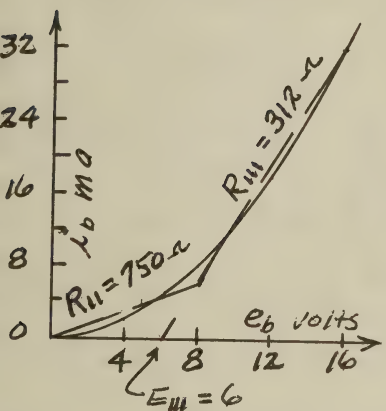
and $K_1 = \dfrac{1}{E_a}$

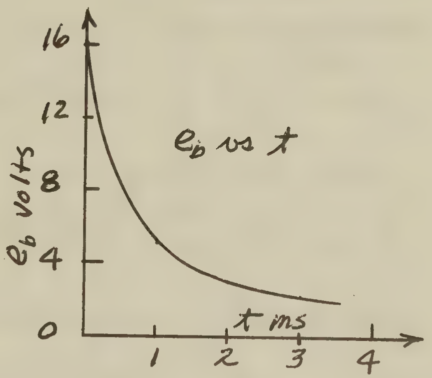
$$e_b = \frac{1}{\frac{kt}{C} + \frac{1}{E_a}}$$

$32 \times 10^{-3} = 16^2 k = 256 k$

$k = 125 \times 10^{-6}$

$$e_b = \frac{1}{125t + 0.0625}$$





(c)
A reasonable approximation is shown above on the curve of i_b vs e_b. The e_b vs t curve for this approximation resembles Curve (4) in Fig 4.13.

4.7 $i = \frac{E}{R+R_1}\left[1-\exp(-t/\tau_1)\right] = \frac{15}{2.25}\left[1-\exp(-t/4.45)\right]$

$R+R_1 = 1+1.25 = 2.25\ k\Omega,\quad \tau_1 = \frac{10\times10^{-3}}{2.25\times10^{3}} = 4.45\ \mu s$

$i(t) = 6.67\left[1-\exp(-t/4.45)\right]$ ma

$i(0^+) = 0,\ e_R(0^+) = e_d(0^+) = 0,\ e_L(0^+) = 15$ V

Time for $e_d = 5$ V and $i = 4$ ma is

$4 = 6.67\left[1-\exp(-\delta_1/4.45)\right]$

$\delta_1 = 0.92\times4.45 = 4.10\ \mu s$

Correction: Top terminal of E in Fig P4.7 should be positive

Expression for i along segment II is

$i(t) = \frac{E-E_{II}}{R+R_{II}}\left[1-\exp(-t/\tau_{II})\right] + i_L(\delta_1)\exp(-t/\tau_{II})$

$i(t) = 8.81\left[1-\exp(-t/8)\right] + 4\exp(-t/8)$

$i(t) = 8.81 - 4.41\exp(-t/8)\ ;\qquad \tau_{II} = \frac{10\times10^{-3}}{1.25\times10^{3}} = 8\ \mu s$

Time δ_{II} for i to go from 4 to 6 ma is

$8 = 8.81 - 4.41\exp(-\delta_{II}/8)$

$\delta_{II} = 1.7\times8 = 13.6\ \mu s$

At $t=\infty$: $i_d = 8.81$ ma

$e_R = 8.81$ V, $e_d = 6.19$ V

$\delta_T = \delta_1 + \delta_{II} = 4.10 + 13.6 = 17.70\ \mu s$

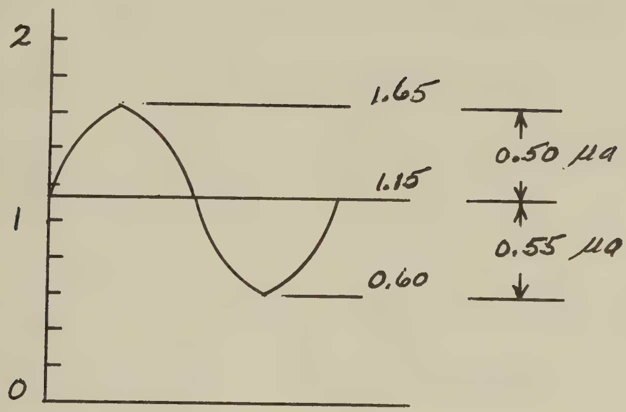
4.8

(a)

0.02 L : 0.60 μa	0.08 L : 1.90 μa
0.04 " : 1.15 "	0.10 " : 1.95 "
0.06 " : 1.65 "	

4.8 (concl)

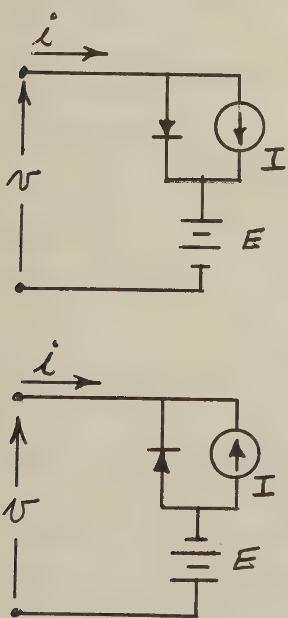
(b)

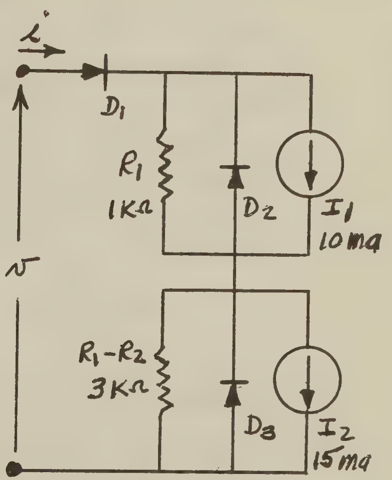


There is a slight amount of nonlinear distortion (approx 2.4% second harmonic) due to the non-uniform spacing in the characteristic curves.

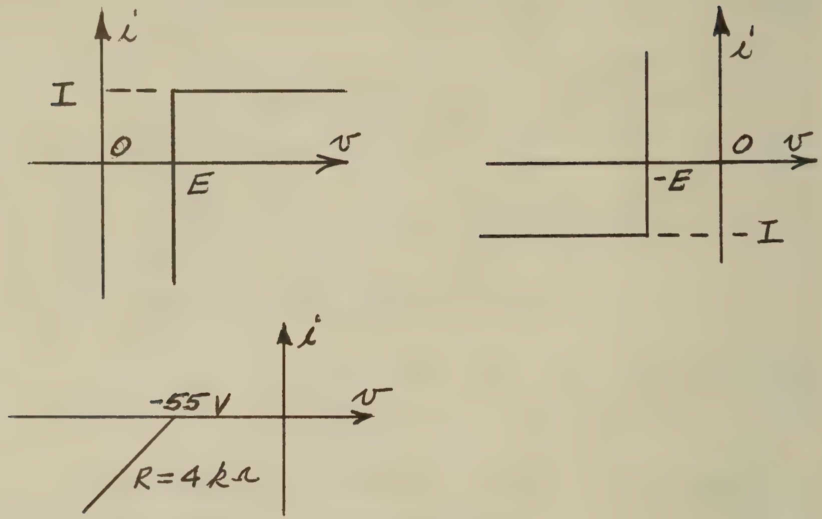
4.9

(a)

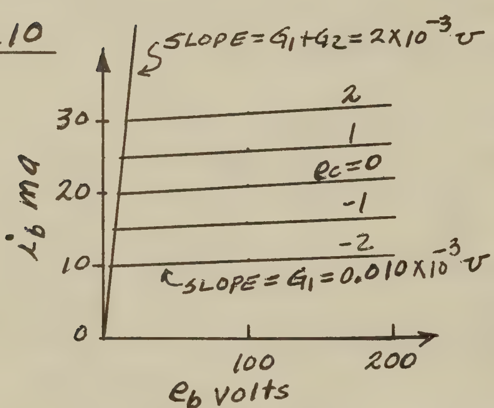




4.9 (Concl.)



4.10



Correction:
The values as given the Prob. for R_1 and R_2 should be interchanged, i.e.,

$$R_1 = 100\ \mathrm{K}\Omega$$
$$R_2 = 500\ \Omega$$

4.11 $\quad i_D = k v_D^2 = I_0 + a_1(v_D - V_0) + a_2(v_D - V_0)^2 + \cdots$

(a) $\quad i_D = I_0 + 2kV_0(v_D - V_0) + k(v_D - V_0)^2 + \cdots$

(b) $\quad i_D(t) = I_0 + 2kV_0 V_{sm} \sin\omega t + kV_{sm}^2 \sin^2\omega t$

(c) $\quad i_D(t) = I_0 + 2kV_0 V_{sm} \sin\omega t + \dfrac{kV_{sm}^2}{2}(1 - \cos 2\omega t)$

4.11 (Concl.)

$$i_0(t) = I_{dc} + I_{d1m}\sin\omega t - I_{d2m}\cos 2\omega t$$

$$I_{dc} = I_0 + \frac{kV_{sm}^2}{2}, \quad I_{d1m} = 2kV_0$$

$$I_{d2m} = \frac{kV_{sm}^2}{2}$$

4.12 A trial-and-error solution of Eq (4.49) yields the following:

(a)

$$\omega t_2 = 427.5^\circ$$

$$E_{L2} = 200\sin 427.5^\circ = 185\ V$$

$$\Delta e_L = 200 - 185 = 15\ V, \quad E_{dc} = 192.5\ V$$

$$I_{cm} = 377 \times 100 \times 10^{-6} \times 200 = 7.54\ a$$

(b) The approximate expressions yield:

$$\Delta e_L = \frac{200}{2 \times 10^3 \times 100 \times 10^{-6} \times 60} = 16.7\ V$$

$$E_{L2} = 200 - 16.7 = 183.3\ V, \quad E_{dc} = 191.35\ V$$

$$\omega t_2 = 426.5^\circ$$

4.13 (a)

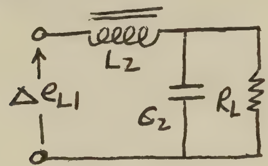
$$E_{dc} = \frac{2 \times 1600}{\pi} - 300 \times 0.20 = 960\ V$$

(b)

$$\Delta e_{L1} = \frac{8 \times 1600}{3\pi}\left[\frac{1}{4(377)^2(10 \times 4 \times 10^{-6})}\right]$$

$\Delta e_{L1} = 60\ V$ (voltage across 1st cap.)

4.13 (Concl.)



$$\Delta e_L \doteq \frac{X_{C2}\,\Delta e_{L1}}{X_{L2}+X_{C2}} \doteq \frac{X_{C2}\,\Delta e_{L1}}{X_{L2}}$$

$$\Delta e_L = \frac{\Delta e_{L1}}{4\omega^2 L_2 C_2} = 0.044\,\Delta e_{L1} = 0.044 \times 60$$

$$\Delta e_L = 2.64 \text{ V}$$

(c) $R_L(\max) \doteq 3\omega L = 3 \times 377 \times 10 = 11{,}300\ \Omega$

4.14

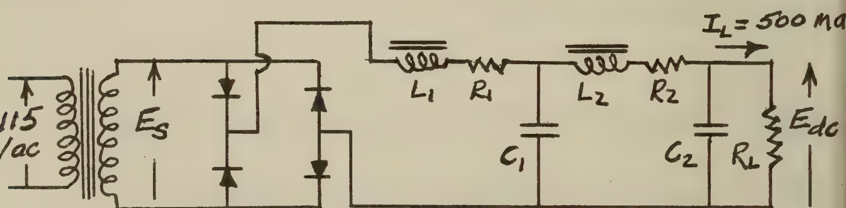
$$i = i_{b1} = i_{b2} + i_{b3} = 2\,i_{b2}$$

$$= 2k\,e_{b2}^{3/2} = k\,e_{b1}^{3/2}$$

$$e = e_{b1} + e_{b2} = \left(\frac{i}{k}\right)^{2/3} + \left(\frac{i}{2k}\right)^{2/3} = \left(\frac{3i}{2k}\right)^{2/3}$$

$$i = \frac{2k}{3}\,e^{3/2}$$

4.15



Given: $E_{dc} = 3000$ V, Ripple factor $= 0.001$
$I_L = 500$ ma

4.15 (concl.) $\Delta e_{L_2} = 0.001 \times 3000 = 3$ V.

$$E_{dc} = 3000 = \frac{2E_{sm}}{\pi} - (R_1 + R_2) I_L$$

To simplify design, assume $L_1 = L_2$, $R_1 = R_2$, and $C_1 = C_2$.

$$E_{sm} = \left(\frac{E_{dc} + 2R_1 I_L}{2}\right)\pi = \frac{3100\pi}{2} = 4870 \text{ V}$$

$$E_s = 0.707 \times 4870 = 3450 \text{ V (rms)}$$

$$\Delta e_{L1} = \frac{8E_{sm}}{3\pi}\left[\frac{1}{4\omega^2 L_1 C_1}\right]; \quad \Delta e_{L2} = \frac{\Delta e_{L1}}{[4\omega^2 L_1 C_1]}$$

$$\frac{1}{[4\omega^2 L_1 C_1]^2} = \frac{3\pi \times 3}{8 \times 4870} = 0.000725$$

$$\frac{1}{4\omega^2 L_1 C_1} = 0.027 \quad \text{and} \quad L_1 C_1 = 65.1 \times 10^{-6}$$

As a trial, assume $L_1 = L_2 = 8$ h, then

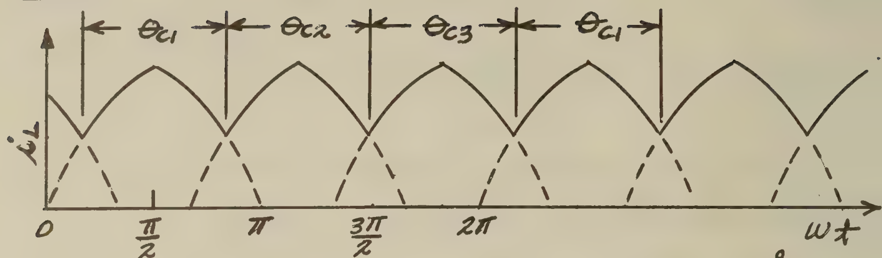
$$C_1 = C_2 = \frac{65.1 \times 10^{-6}}{8} = 8.13\,\mu f$$

A stepup power transformer having a transformation ratio of

$$\frac{E_s}{115} = \frac{3450}{115} = 30$$

is required.

4.16



conduction angles $\theta_{c1} = \theta_{c2} = \theta_{c3} = 120^\circ$

(b) $$I_L(ave) = \frac{6}{4\pi}\int_{\pi/6}^{5\pi/6} \frac{E_{sm}}{R_L} \sin\omega t \, d(\omega t)$$

$$= \frac{6}{4\pi}\frac{E_{sm}}{R_L}\sqrt{3} = 0.828\frac{E_{sm}}{R_L}$$

$$I_L(rms) = \frac{0.838\, E_{sm}}{R_L}$$

(c) $$\text{ripple} = \Delta i_L = \frac{E_{sm}}{2R_L} = \frac{I_{Lm}}{2}$$

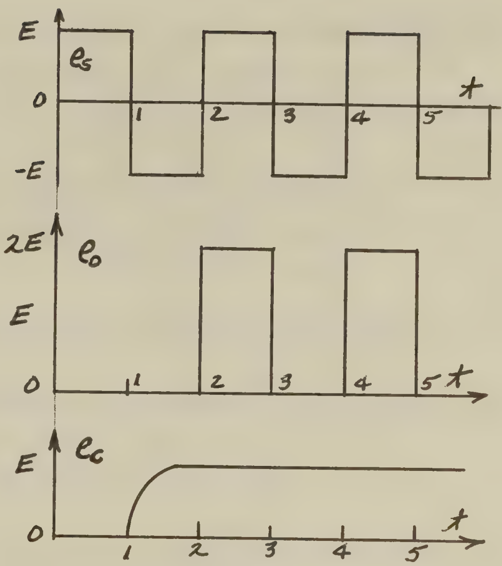
(d) PIV across D_2 occurs at $\omega t = 60^\circ$, i.e.

$$v_{D2} = e_{2n} - e_{1n} = E_{sm}[\sin(\omega t - 120^\circ) - \sin\omega t]$$

$$v_{D2}(max) = E_{sm}[-0.866 - 0.866] = \sqrt{3}\,E_{sm}$$

$\therefore$ PIV $= \sqrt{3}\,E_{sm}$

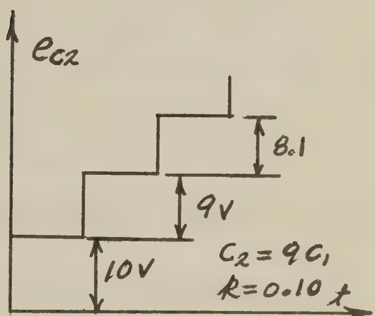
4.17



(b) The time constant RC affects the initial buildup of e_c to its final value E.

4.18

The adjacent plot shows that the performance of the storage counter is essentially the same for positive pulses as for negative pulses. The step increases in e_{c2} are the same.



Buildup of e_{c2} for the case of 100 volt positive pulses.

4.19 Input e_s is series of positive pulses of amplitude E_s, period T, and repetition rate $f = 1/T$.

First charging cycle:

(1) C_1 and C_2 charge instantaneously to

4.19 (Concl.)

$(1-k)E_s$ and kE_s, and I jumps to $e_{c2}/R = kE_s/R$.

(2) During remainder of charging cycle e_{c2} and I decrease exponentially & e_{c1} increases

First discharging cycle:

(1) C_1 discharges instantaneously to zero, and e_{c2} and I decrease exponentially as C_2 discharges into R.

In subsequent charging cycles e_{c2} and I increase since they do not completely decrease to zero during the discharge cycle. Finally a steady condition obtains in which the charge gained and lost are equal, i.e., $i_{c2}(ave) = 0$.

The change in e_{c1} under SS conditions is

$$\Delta e_{c1} = E_s - e_{c2} = E_s - kE_s = (1-k)E_s$$

$$\Delta q_1 = C_1 \Delta e_{c1} = C_1(1-k)E_s$$

For $C_2 >> C_1$, $k = \frac{C_1}{C_1+C_2}$, $(1-k) \doteq 1$

$\Delta q_1 \doteq C_1 E_s$ amount of charge supplied to C_1 and C_2 during each charging cycle.

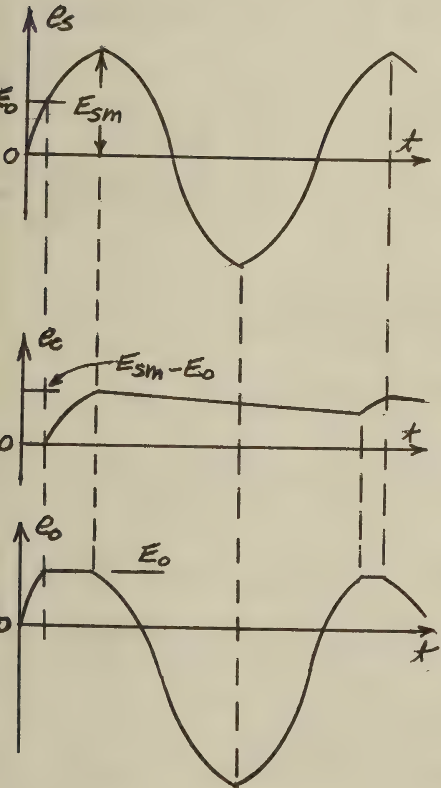
$$I_{chg}(ave) = I_{ave} = \frac{\Delta q_1}{T} \doteq \frac{C_1 E_s}{T} = C_1 f E_s$$

$$f \doteq \frac{I_{ave}}{C_1 E_s}$$

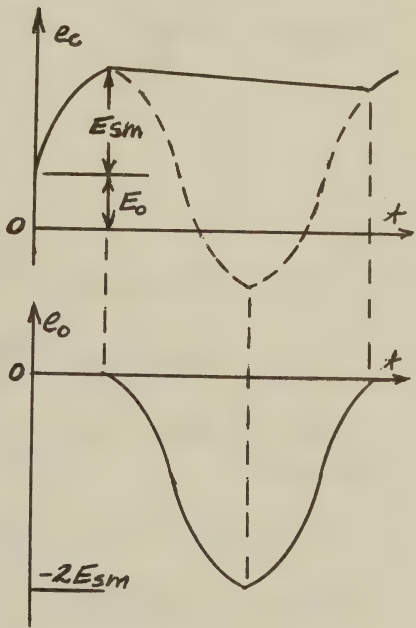
4.20 No, the operation is not altered by inserting a voltage E_o in series with e_s. The capacitors C_1 and C_2 charge to higher voltages, and C_1 discharges down to E_o instead of zero as in Prob. 4.19. The average current I_{ave} indicated by the meter remains the same.

4.21 Assume e_s is a sinusoidal waveform and

$$e_s = E_{sm} \sin \omega t \text{ and } E_{sm} > E_o \text{ and } RC \gg \frac{1}{f}$$



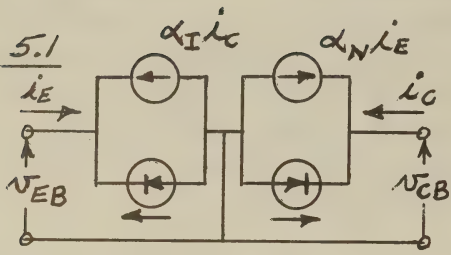
Waveforms for left hand circuit.

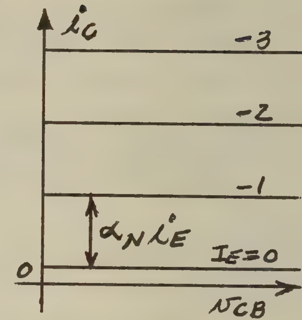


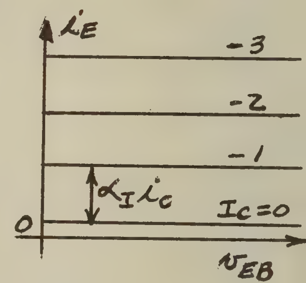
Waveforms for right hand circuit.

CHAPTER 5

5.1







$$i_E = -I_{EO}\left[\exp\left(-\frac{v_{EB}}{\phi}\right)-1\right]-\alpha_I i_C$$

$$i_C = -I_{CO}\left[\exp\left(-\frac{v_{CB}}{\phi}\right)-1\right]-\alpha_N i_E$$

Where $\phi = \dfrac{kT}{e}$

5.2

$$i_C = -I_{CO}\left[\exp\left(-\frac{v_{CB}}{\phi}\right)-1\right]-\alpha_N i_E$$

$$i_E = -I_{EO}\left[\exp\left(-\frac{v_{EB}}{\phi}\right)-1\right]-\alpha_I i_C$$

Solving these equations simultaneously, we obtain

$$i_C = -I_{CS}\left[\exp\left(-\frac{v_{CB}}{\phi}\right)-1\right]+\alpha_N I_{ES}\left[\exp\left(-\frac{v_{EB}}{\phi}\right)-1\right]$$

$$i_E = -I_{ES}\left[\exp\left(-\frac{v_{EB}}{\phi}\right)-1\right]+\alpha_I I_{CS}\left[\exp\left(-\frac{v_{CB}}{\phi}\right)-1\right]$$

where $\phi = \dfrac{kT}{e}$, $I_{CS} = \dfrac{I_{CO}}{1-\alpha_N\alpha_I}$,

$I_{ES} = \dfrac{I_{EO}}{1-\alpha_N\alpha_I}$

5.3 From Eq(5.15), we have

$$i_C = I_{CS}\left[\exp\left(\frac{v_{CB}}{Q}\right)-1\right] - \alpha_N I_{ES}\left[\exp\left(\frac{v_{EB}}{Q}\right)-1\right]$$

For the amplification or active mode, this expression simplifies to

$$i_C = -I_{CS} - \alpha_N I_{ES}\left[\exp\left(\frac{v_{EB}}{Q}\right)\right] \doteq -\alpha_N I_{ES}\exp\left(\frac{v_{EB}}{Q}\right)$$

$$di_C \doteq -\frac{\alpha_N I_{ES}}{Q}\exp\left(\frac{v_{EB}}{Q}\right) dv_{EB} = -\frac{i_C}{Q} dv_{EB}$$

Which agrees with Eq (5.20).

5.4

$$i_C = I_{CO}\left[\exp\left(\frac{v_{CB}}{Q}\right)-1\right] - \alpha_N i_E$$

$$\exp\left(\frac{v_{CB}}{Q}\right) = \frac{i_C + \alpha_N i_E + I_{CO}}{I_{CO}}$$

$$v_{CB} = Q \ln\left[\frac{i_C + \alpha_N i_E + I_{CO}}{I_{CO}}\right]$$

$$i_E = I_{EO}\left[\exp\left(\frac{v_{EB}}{Q}\right)-1\right] - \alpha_I i_C$$

$$v_{EB} = Q \ln\left[\frac{i_E + \alpha_I i_C + I_{EO}}{I_{EO}}\right]$$

5.5 (a)

$$n_{eo} = (2.4\times10^{13})^2/2\times10^{17} = 2.88\times10^{9} \text{ elec/cm}^3$$

$$n_{co} = (2.4\times10^{13})^2/4\times10^{16} = 1.44\times10^{10} \text{ elec/cm}^3$$

$$p_{bo} = (2.4\times10^{13})^2/5\times10^{14} = 1.152\times10^{12} \text{ holes/cm}^3$$

5.5 (concl.)

$$n_e(0) = 2.88\times10^{9}\exp(100/26) = 1.35\times10^{11}$$

$$p_b(0) = 1.152\times10^{12}\exp(100/26) = 5.42\times10^{13}$$

$$p_b(W) = 1.152\times10^{12}\exp(-500/26) = 5.07\times10^{3}$$

$$n_c(0) = 1.44\times10^{10}\exp(-500/26) = 6.34\times10^{3}$$

$$\frac{I_c\,(Ge)}{I_c\,(Si)} = \frac{D_p\,(Ge)}{D_p\,(Si)}\cdot\frac{[p_b(0)-p_b(W)]\,(Ge)}{[p_b(0)-p_b(W)]\,(Si)}$$

$$= \frac{49\times10^{-4}\times5.42\times10^{13}}{13\times10^{-4}\times2.12\times10^{7}} = 9.65\times10^{6}$$

5.6 $r_b + r_{cr} \doteq \dfrac{20-0}{2.1-1.9} = \dfrac{20}{0.20} = 100\,K\Omega$

$r_b + r_{cf} \doteq \dfrac{0.80-0.10}{8} = \dfrac{0.70}{8} = 0.875\,K\Omega = 875\,\Omega$

α cannot be accurately determined. This is not a practical method for determining parameters.

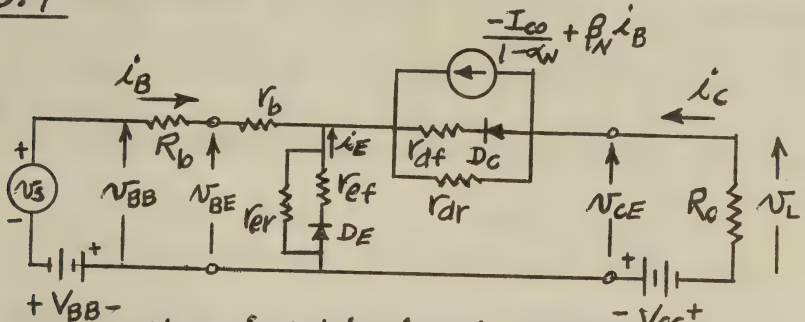
5.7 $r_e + r_{dr} = \dfrac{20}{2.5-1.8} = \dfrac{20}{0.70} = 28.6\,K\Omega$

$$\beta_N = \frac{1\times10^{-3}}{(60-20)\times10^{-6}} = \frac{1}{0.04} = 25$$

Not a practical method for determining parameters.

5.8 Verification of numerical equations given Eqs. (5.56), (5.57), and (5.63).

5.9



Numerical data given in Fig 5.16.

BP₁ OF D_E $\quad i_E = i_{DE} = 0$ so $i_C = -i_B$

$$V_{CC} = (R_C + r_{dr}) i_C - \beta_N r_{dr} i_B = 0$$

$$i_B = -i_C = \frac{-V_{CC}}{R_C + (\beta_N + 1) r_{dr}} = \frac{20}{5+500} = 0.0396 \text{ ma}$$

$$v_{BE} = r_b i_B = 0.200 \times 0.0369 = 0.008 \text{ Volts}$$

$$v_L = -R_C i_C = -5(-0.0396) = 0.198 \text{ volts}$$

BP₂ OF D_C $\quad i_C = \beta_N i_B \quad$ Now $i_{DC} = v_{DC} = 0$, so

$$V_{CC} = R_C i_C + r_{ef}(i_C + i_B) = \left(R_C + r_{ef} + \frac{r_{ef}}{\beta_N}\right) i_C$$

$$i_C = \frac{-20}{5 + \frac{0.025(20)}{19}} = -3.98 \text{ ma}$$

$i_B = -20.9\,\mu a$, $v_L = +19.85$, $v_{BB} = -4.15$

5.10

Since the assumed current directions and voltage polarities are the same for the pnp and the npn transistor, the equations derived in Sections 5.14 and 5.15 apply for the npn transistor. By changing the signs of the numerical values given in Section 5.19 and Fig 5.20, we obtain the equations and waveforms for the npn transistor. For example

$$i_B = I_B + I_{bm} \sin \omega t = 100 + 50 \sin \omega t$$

$$i_C = I_C + I_{cm} \sin \omega t = 2.26 + 0.80 \sin \omega t$$

$$v_{CE} = V_{CE} - V_{cem} \sin \omega t = 8.70 - 4.0 \sin \omega t$$

5.11

The emitter and the collector loop equations for the circuit in Fig P5.11 are

$$v_{EE} = v_S + V_{EE} = (R_e + r_e + r_b) i_E + r_b i_C$$

$$V_{CC} - r_c I_{CO} = (r_b + \alpha_N r_c) i_E + (r_b + r_c + R_C) i_C$$

Solving these equations simultaneously for i_E and i_C, we obtain the equations given in the problem.

5.12 Cutoff state expressions

$$v_{EE} \doteq v_{EB} = 501\, i_E - 0.008 \doteq 501\, i_E$$

$$v_L = 0.0094\, v_{EE} + 0.20$$

$$v_L = 0.0094\, v_{EB} + 0.20$$

5.12 (Concl.)

Amplification state expressions

$v_{EE} = 1.004\, i_E - 0.008$

$v_{EB} = 0.037\, i_E - 0.008$

$v_L = 4.67\, v_{EE} + 0.23, \quad A_v' = \dfrac{\Delta v_L}{\Delta v_{EE}} = 4.67$

$v_L = 128\, v_{EB} + 1.21, \quad A_v = \dfrac{\Delta v_L}{\Delta v_{EB}} = 128$

Saturation state expressions

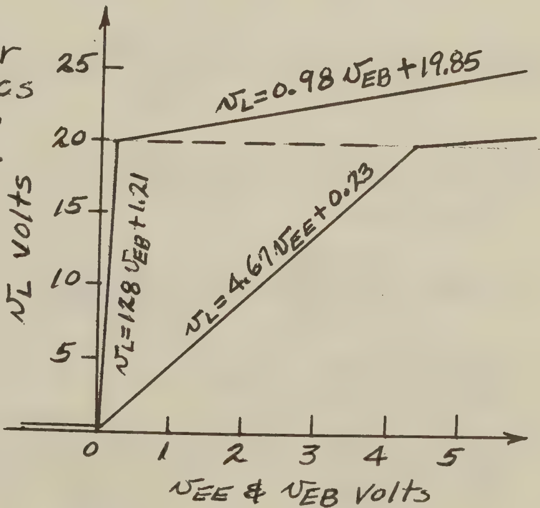
$v_{EE} = 1.18\, i_E - 0.765$

$v_{EB} = 0.215\, i_E - 0.765$

$v_L = 0.181\, v_{EE} + 19.3$

$v_L = 0.98\, v_{EB} + 19.85$

only the transfer characteristics are plotted. The input character- istics are read- ily obtained from the above expressions.



5.13 (a) $I_B = \dfrac{V_{BB} - V_{BE}}{R_b} = \dfrac{2-0}{50} = 0.040\text{ ma} = 40\,\mu\text{a}$

From load line: $I_C = 4.5\text{ ma},\ V_{CE} = 4.5\text{ V}$

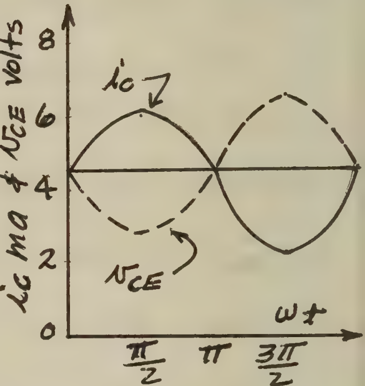
(b) $i_B(t) = 40 + 20 \sin \omega t\ \ \mu\text{a}$

$i_C(\max) = 6.2\text{ ma}$

$i_C(\min) = 2.4\text{ ma}$

$v_{CE}(\max) = 6.6\text{ V}$

$v_{CE}(\min) = 2.8\text{ V}$



(c) $P_C = V_{CE} I_C = 4.5 \times 4.5$
$= 20.3\text{ mW}$

(d) $A_i = \dfrac{6.2 - 2.4}{0.06 - 0.02} = 95$

$P_{RC} = \left(\dfrac{3.8 \times 10^{-3}}{2}\right)^2 \dfrac{1 \times 10^3}{2} = 1.8\text{ mW}$

5.14 (a) $R_b = \dfrac{V_{CC} - V_{BE}}{I_B} = \dfrac{9}{0.04} = 225\text{ K}\Omega$

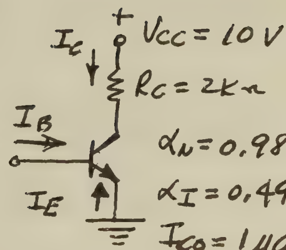
(b) Using same values V_{BB} & R_b from Prob 5.13, we have

$$V_{BB} = \frac{R_1 V_{CC}}{R_1 + R_2} = \frac{R_1 R_2 V_{CC}}{(R_1 + R_2) R_2} = \frac{R_b V_{CC}}{R_2}$$

$$R_2 = \frac{50 \times 9}{2} = 225\text{ K}\Omega$$

$$R_b = \frac{R_1 R_2}{R_1 + R_2} \quad \text{or} \quad R_1 = \frac{R_b R_2}{R_2 - R_b} = \frac{50 \times 225}{225 - 50} = 64.25\text{ K}\Omega$$

5.15 (a) $I_C = I_{CO} - \alpha_N I_E$



$\alpha_N = 0.98$

$\alpha_I = 0.49$

$I_{CO} = 1\,\mu a$

$I_{EO} = .5\,''$

$I_C = I_{CO} + \alpha_N I_C$

$I_C = -I_E = \dfrac{1}{1-0.98} = 50\,\mu a$

(b) $I_C = I_{CO} - \alpha_N I_E$

$I_E = I_{EO} - \alpha_I I_C$

$$I_C = \frac{I_{CO} - \alpha_N I_{EO}}{1 - \alpha_N \alpha_I} = \frac{1 - .98(.50)}{1-(.98)(.49)} = 0.98\,\mu a$$

$$I_E = \frac{I_{EO} - \alpha_I I_{CO}}{1 - \alpha_N \alpha_I} = \frac{.50 - .49(1)}{1 - 0.48} = 0.019\,\mu a$$

(c) $I_C = I_{CO} - \alpha_N I_E$

Since $V_{BE} = 0$, $I_E = -I_{EO}[1-1] - \alpha_I I_C = -\alpha_I I_C$

$$I_C = \frac{I_{CO}}{1 - \alpha_N \alpha_I} = \frac{1}{1-0.48} = 1.92\,\mu a$$

$I_E = -\alpha_I I_C = -0.49 \times 1.92 = 0.942\,\mu a$

5.16 (a) $I_C = \dfrac{-I_{CO}}{1-\alpha_N} + \beta_N I_B$

$I_B = \dfrac{V_{CC} - V_{BE}}{R_b} \doteq \dfrac{-15}{200} = -75\,\mu a$

$I_C = -50(0.001) + 49(-0.75) = -3.72\,ma$

$I_E = 3.72 + 0.075 = 3.795\,ma$

<u>5.16 (Concl.)</u> $V_{CE} = V_{CC} - R_C I_C = -15 - 3(-3.72$

$= -3.84$ volts

<u>From Prob 5.4</u>

$$v_{EB} = \phi \ln\left[\frac{I_E + I_{EO} + \alpha_I I_C}{}\right]$$

$$= 25 \ln\left[\frac{3.795 + 0.0005 - 1.825}{0.0005}\right] = 208 \text{ mv}$$

(b) YES, because $V_{CE} = -3.84$ & $V_{EB} = .208$ v

<u>5.17</u> Assume active state, then:

$$I_B = \frac{-15}{100} = -0.150 \text{ ma}$$

$$I_C = -50(0.001) - 49(0.150) = -7.40 \text{ ma}$$

$$V_{CE} = -15 - (3)(7.40) = -15 + 22.20 = 7.20 \text{ V}$$

V_{CE} has gone positive, so transistor is operating in saturation state.

$$I_C \doteq \frac{V_{CC}}{R_C} = \frac{-15}{3} = -5 \text{ ma} \quad \& \quad I_E = 5.150 \text{ ma}$$

$$V_{EB} = 25\left[\frac{5.150 + 0.0005 - 3.62}{0.0005}\right] = 200 \text{ mv}$$

$$V_{CB} = 25\left[\frac{-5.00 - 0.001 + .98(5.150)}{1 \times 10^{-3}}\right] = 125 \text{ mv}$$

$$V_{CE} = V_{CB} - V_{EB} = 125 - 200 = -75 \text{ mv}$$

5.18 From Eq (5.89):

$\omega t = 90°$: $i_c(max) = I_c + I_{c2m} + I_{c1m} + I_{c2m}$

$\omega t = 270°$: $i_c(min) = I_c + I_{c2m} - I_{c1m} + I_{c2m}$

Solving these two equations, we get

$$I_{c1m} = \frac{i_c(max) - i_c(min)}{2}$$

$$I_{c2m} = \frac{i_c(max) + i_c(min) - 2I_c}{4}$$

(b) $I_{c1m} = \dfrac{3.40 - 1.10}{2} = 1.15\,a$ (TEXT value is 1.18a)

$I_{c2m} = -0.075\,a$ (same as Text value)

5.19 (a) $i_c(max) = 6.2$, $i_c(min) = 2.4$, $I_c = 4.5$ ma

$I_{c1m} = 1.9$ ma, $I_{c2m} = -0.10$ ma

$$P_{Rc} = \frac{(1.9 \times 10^{-3})^2 \times 1000}{2} = 1.80 \text{ mW}$$

$$\%\ 2^{nd} = \frac{0.10}{1.90} \times 100 = 5.26\,\%$$

(b) $i_c(max) = 7.6$, $i_c(min) = 0.40$, $I_c = 4.5$ ma

$I_{c1m} = 3.6$, $I_{c2m} = -0.25$ ma

$$P_{Rc} = \frac{(3.6 \times 10^{-3})^2 \times 1000}{2} = 6.5 \text{ mw}$$

$$\%\ 2^{nd} = \frac{0.25}{3.6} \times 100 = 6.95\,\%$$

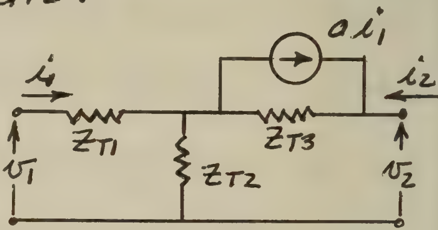
$V_{cc} I_c = 9(4.5) = 40.5$ mw (quiescent)

$V_{cc}(I_c + I_{c2m}) = 9(4.5 - 0.25) = 38.2$ mw (signal)

5.20 The terminal equations for FIGS 5.25(a) and (b) are:

$v_1 = z_{11} i_1 + z_{12} i_2 \quad (1)$

$v_2 = z_{21} i_1 + z_{22} i_2 \quad (2)$



$$v_1 = (Z_{T1} + Z_{T2}) i_1 + Z_{T2} i_2 \qquad (3)$$

$$v_2 = (Z_{T2} + a Z_{T3}) i_1 + (Z_{T2} + Z_{T3}) i_2 \qquad (4)$$

Comparing Eqs (1) & (3), we get

$$z_{11} = Z_{T1} + Z_{T2}, \quad \boxed{z_{12} = Z_{T2}}, \quad \boxed{Z_{T1} = z_{11} - z_{12}}$$

Comparing Eqs (2) & (4), we get

$$z_{21} = Z_{T2} + a Z_{T3} = z_{12} + a Z_{T3}$$

$$a Z_{T3} = z_{21} - z_{12}, \quad z_{22} = Z_{T2} + Z_{T3} = z_{12} + Z_{T3}$$

$$a = \frac{z_{21} - z_{12}}{Z_{T3}} \qquad \boxed{Z_{T3} = z_{22} - z_{12}}$$

$$\boxed{a = \frac{z_{21} - z_{12}}{z_{22} - z_{12}}}$$

5.21 The terminal equations for the z-parameter model in Fig 5.25(a) and for the Tee model of the CB connection in Fig 5.25(c) are as follows:

$v_1 = z_{11} i_1 + z_{12} i_2 \quad (1)$

$v_2 = z_{21} i_1 + z_{22} i_2 \quad (2)$

5.21 (Concl.)

$$v_{eb} = v_1 = (r_b + r_e) i_e + r_b i_c \quad (3)$$

$$v_{cb} = v_2 = (r_b + \alpha_N r_c) i_e + (r_b + r_c) i_c \quad (4)$$

Comparing Eqs (1) & (3) and (2) & (4) we get

$$z_{11} = r_b + r_e \qquad z_{21} = r_b + \alpha_N r_c$$

$$z_{12} = r_b \qquad z_{22} = r_b + r_c$$

The relationships given in Figs 5.25(d) & (e) for the CE and the CC connections are determined in a similiar manner.

5.22 From Fig. 5.27(b), we obtain

$$v_1 = h_{11} i_1 + h_{12} v_2 \ (1), \qquad v_2 = -R_L i_2 \ (3)$$

$$i_2 = h_{21} i_1 + h_{22} v_2 \ (2), \qquad i_2 = -Y_L v_2 \ (4)$$

From Eq (2) & Eq (3),

$$i_2 = h_{21} i_1 + h_{22}(-R_L i_2) \ \& \ A_i = \frac{h_{21}}{1 + h_{22} R_L}$$

From Eqs (1) & (3),

$$v_1 = h_{11} i_1 - h_{12} R_L i_2 = h_{11} i_1 - h_{12} R_L A_i i_1$$

$$R_i = \frac{v_1}{i_1} = h_{11} - h_{12} R_L A_i = h_{11} - \frac{h_{12} h_{21}}{h_{22} + Y_L}$$

From Eq (1), $v_1 = h_{11} i_2 / A_i + h_{12} v_2$

$$= \frac{h_{11}(1 + h_{22} R_L)(-v_2)}{h_{21} R_L} + h_{12} v_2$$

5.22 (Concl.)

$$A_v = \frac{v_2}{v_1} = \frac{h_{21} R_L}{h_{12} h_{21} R_L - h_{11}(1 + h_{22} R_L)}$$

Setting v_s in Fig 5.27 (b) equal to zero and solving for i_1, we get

$$i_1 = \frac{-h_{12} v_2}{h_{11} + R_s}$$

Substituting this expression for i_1 in Eq (2), the expression for R_o is obtained.

$$R_o = \frac{v_2}{i_2} = \frac{h_{11} + R_s}{(h_{11} + R_s) h_{22} - h_{12} h_{21}}$$

5.23 From Fig 5.25 (d), we have

$$r_{11} = r_b + r_e \qquad r_{21} = r_e - \alpha_N r_c$$

$$r_{12} = r_e \qquad r_{22} = r_e + (1 - \alpha_N) r_c$$

Substituting these relations into the 3-parameter equations listed in Table 5.3, we obtain the CE expressions listed in Table 5.5(b).

5.24

$$v_1 = h_{11} i_1 + h_{12} v_2 \qquad v_1 = r_{11} i_1 + r_{12} i_2$$

$$i_2 = h_{21} i_1 + h_{22} v_2 \qquad v_2 = r_{21} i_1 + r_{22} i_{22}$$

Now let $i_1 = 0$ and $i_2 = 1$, then

5.24 (concl.)

$$v_2 = \frac{i_2}{h_{22}} = r_{22} i_2, \quad \text{so} \quad r_{22} = \frac{1}{h_{22}}$$

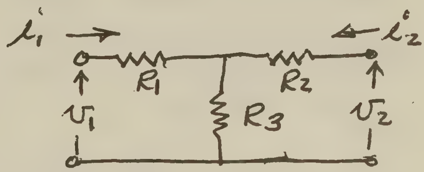
$$v_1 = h_{12} v_2 = \frac{h_{12} i_2}{h_{22}} = r_{12} i_2, \text{ so } r_{12} = \frac{h_{12}}{h_{22}}$$

Now let $i_1 = 1$ and $i_2 = 0$, then

$$v_1 = h_{11} + h_{12} v_2 = r_{11} \quad \text{and} \quad v_2 = -\frac{h_{21} i_1}{h_{22}}$$

$$h_{11} - \frac{h_{12} h_{21}}{h_{22}} = r_{11} \quad \text{and} \quad r_{21} = \frac{-h_{21}}{h_{22}}$$

5.25



$$i_1 = y_{11} v_1 + y_{12} v_2$$

$$i_2 = y_{21} v_1 + y_{22} v_2$$

Let $v_2 = 0$ (output shorted);

$$i_1 = y_{11} v_1 = \frac{v_1}{R_1 + \frac{R_2 R_3}{R_2 + R_3}} \quad \& \quad y_{11} = \frac{R_2 + R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3}$$

$$i_2 = y_{21} v_1 = \frac{-R_3 i_1}{R_2 + R_3} = \frac{-R_3 y_{11} v_1}{R_2 + R_3}$$

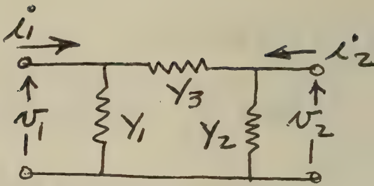
$$y_{21} = \frac{-R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3}$$

Let $v_1 = 0$ and using similiar method, we get

$$y_{12} = \frac{-R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3} \quad \& \quad y_{22} = \frac{R_1 + R_3}{R_1 R_2 + R_1 R_3 + R_2 R_3}$$

5.25 (concl.)

Using an identical procedure, we obtain the following expressions:

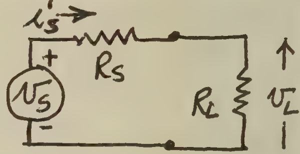


$$y_{11} = Y_1 + Y_3 \qquad y_{21} = -Y_3$$

$$y_{22} = Y_2 + Y_3 \qquad y_{12} = -Y_3$$

5.26

For the circuit in Fig 5.57 (b), we have an output power p_L of



$$p_L = -v_2 i_2 \qquad p_s = v_L i_s = \frac{R_L v_S^2}{(R_S+R_L)^2}$$

$$G_i = \frac{-v_2 i_2}{v_L i_s} = \frac{+(R_S+R_L)^2 v_2^2}{R_L^2 v_S^2} = \frac{(R_S+R_L)^2}{R_L^2}(A_v')^2$$

From Table 5.3 we substitute for A_v', and

$$G_i = \frac{(R_S+R_L)^2 h_{21}^2}{[(h_{11}+R_S)(h_{22}R_L+1) - h_{12}h_{21}R_L]^2}$$

$$G_i = \frac{(R_S+R_L)^2 r_{21}^2}{[r_{12}r_{21} - (r_{11}+R_S)(r_{22}+R_L)]^2}$$

5.27 $V_o = \dfrac{100 R_L V_i}{r_o + R_L} = \dfrac{100 \times 5000\, V_i}{50{,}000 + 5000}$

$$A_v = \frac{V_o}{V_i} = 9.09$$

$$A_v' = \frac{r_i A_v}{r_i + R_S} = \frac{100 \times 9.09}{100 + 1000} = 0.825$$

$$G = A_v^2 \frac{r_i}{R_L} = (9.09)^2 \left(\frac{100}{5000}\right) = 1.65$$

$$G_t = (A_v')^2 \frac{4R_S}{R_L} = (0.825)^2 \frac{(4 \times 1000)}{5000} = 0.543$$

$$G_i = \frac{V_o^2}{V_S^2} \left[\frac{R_L + R_S}{R_L}\right]^2 = (0.825)^2 \left(\frac{6}{5}\right)^2 = 0.980$$

$$G_A = \frac{V_o^2}{V_S^2} \cdot \frac{4 r_i}{r_o} = (A_v')^2 \frac{4 r_i}{r_o}$$

$$A_v' = \frac{100\, r_o}{r_o + r_o} \cdot \frac{r_i}{r_i + r_i} = 50 \times 0.50 = 25$$

$$G_A = \frac{(25)^2 \times 4 \times 100}{50{,}000} = 5$$

5.28 (a) $I_C = (50+1)(-3) = -153\ \mu a$

$$I_C = -153 + 50(-50) = -2653\ \mu a$$

(b) $\left.\begin{aligned} I_{CO}(55^\circ c) &= 10(-3) = -30\ \mu a \\ h_{FE}(55^\circ c) &= 1.4(50) = 70 \end{aligned}\right\}$ From Fig 5.36

5.28 (concl.)

$$I_c = (70+1)(-30) = -2130\ \mu a$$

$$I_c = -2130 - 70(-50) = -5630\ \mu a$$

(c) $$\frac{I_c(55°)}{I_c(25°)} = \frac{5630}{2653} = 2.12$$

From Figs 5.36(a) and (b) at $V_{CE} = 10$ V

$$\frac{I_c(55°)}{I_c(25°)} = \frac{7.40\ ma}{3.50\ ma} = 2.11$$

5.29

$$I_{co}(25°) = -1\ \mu a, \quad I_{co}(75°) = (2)^5(-1) = -32\ \mu a$$

$$S_I = \frac{\Delta I_c}{\Delta I_{co}} = \frac{250}{32-1} = 8.07$$

$$R_e = \frac{2\ \text{volts}}{I_E} = \frac{2}{3.54} = 0.565\ k\Omega = 565\ \Omega$$

$$V_{cc} = V_{CE} + R_c I_c - V_E = -6.5 - 3.5 - 2 = -12\ v$$

$$\frac{R_b}{R_e} = \frac{(\beta_N+1)(S_I-1)}{(\beta_N+1) - S_I} = \frac{81 \times 7.07}{81 - 8.07} = 7.85$$

$$R_b = 7.85 \times 0.565 = 4.43\ k\Omega$$

$$V_{BB} = 4.43(-0.04) - 0.15 - 2 = -2.33\ v$$

$$V_{BB} = \frac{R_1 V_{cc}}{R_1 + R_2} = \frac{R_b V_{cc}}{R_2}, \quad R_2 = \frac{4.43 \times 12}{2.33} = 22.8\ k\Omega$$

$$R_1 = \frac{R_2 R_b}{R_2 - R_b} = \frac{22.8 \times 4.43}{22.8 - 4.43} = 5.50\ k\Omega$$

5.30 Taking the derivative of Eq (5.142) with respect to V_{BE} yields

(a)

$$S_V = \left.\frac{\partial I_C}{\partial V_{BE}}\right|_{I_{CO},\beta_N} = \frac{-\beta_N}{R_b+(\beta_N+1)R_e}$$

(b)

$$S_V = \frac{-50}{[6.80+(50+1)(1.33)]10^3} = -0.67\times10^{-3}$$

5.31 Taking the derivative of Eq (5.142) with
(a) respect to β_N, we obtain

$$\frac{\partial I_C}{\beta_N} = \frac{\beta_N[(V_{BB}-V_{BE})+(R_b+R_e)I_{CO}]}{\beta_N[R_b+(\beta_N+1)R_e]} - \frac{R_e I_C}{R_b+(\beta_N+1)R_e}$$

$$\doteq \frac{I_C}{\beta_N} - \frac{R_e I_C}{R_b+(\beta_N+1)R_e}, \quad \text{For } \beta_N+1 \doteq \beta_N$$

$$S_{\beta_N} \doteq \frac{(R_b+R_e)I_C}{\beta_N[R_b+(\beta_N+1)R_e}$$

(b)

$$S_{\beta_N} = \frac{(6.80+1.33)(3.6\times10^{-3})}{50[6.80+51(1.33)]} = 0.784\times10^{-5}\ a$$

$$= 0.784\times10^{-2}\ ma$$

5.32 (a) $I_C(25^\circ) = 81(.50)+80(20) = 1640\ \mu a$

(b) $I_C(55^\circ) = (2)^5(0.50)(81)+1600 = 2900\ \mu a$

(c)

$$S_I = \frac{\Delta I_C}{\Delta I_{CO}} = \frac{2900-1640}{16-0.50} = 81.3$$

5.33 (a) $V_{BB} = \dfrac{6.67 \times 12}{6.67 + 20} = 3\ V$

$R_b = \dfrac{6.67 \times 20}{26.67} = 5\ K\Omega$, $\beta_N = \dfrac{0.986}{1-0.986} = 70.5$

$I_B = \dfrac{V_{BB} - V_{BE}}{R_b + (\beta_N + 1) R_e} \doteq \dfrac{3}{5 + 71.5(0.50)} = 0.0737\ ma$

$I_C = 71.50(0.001) + 70.5(0.0737) = 5.27\ ma$

$V_{CE} = 12 - 1(5.27) - 0.5(5.27 + 0.0737) = 4.06\ V$

(b) Assume $V_{BE} = 0.20\ V$

$I_B = \dfrac{3 - 0.20}{40.7} = 0.069\ ma$

$I_C = 0.071 + 70.5(0.069) = 4.92\ ma$

$V_{CE} = 12 - 1(4.92) - 2.50 = 4.58\ V$

Error in $I_C = \dfrac{5.27 - 4.92}{4.92} = \dfrac{0.35}{4.92} = 7.1\%$

5.34 (a) From load line: $R_c + R_e = \dfrac{8}{4.5} = 1.775\ k\Omega$

$R_c = 1.775 - 0.20 = 1.575\ k\Omega$

$R_1 = \dfrac{V_{CC} - V_{BE} - R_e(I_C + I_B)}{I_B} = \dfrac{8 - 0 - 0.20(2.3 + 0.02)}{0.02}$

$R_1 = 377\ k\Omega$,

(b) $R_{ac} = \dfrac{1.575 \times 2}{1.575 + 2} = 0.882\ k\Omega$

5.34 (Concl.)

$$I_{cm} = \frac{4 - 0.5}{2} = 1.75 \text{ ma}$$

(c)

$$I_{Lm} = \frac{1.575 \times 1.75}{1.575 + 2} = 0.772 \text{ ma}$$

$$A_i = \frac{I_{Lm}}{I_{bm}} = \frac{0.772}{0.020} = 38.6$$

$$P_L = \frac{(0.772 \times 10^{-3})^2 \times 2 \times 10^3}{2} = 0.597 \text{ mW}$$

5.35 $R_E' = R_1 \| R_2 \| R_E = 10 \| 90 \| 2 = 1.64 \text{ k}\Omega$

$$i_b = k i_s = \frac{R_3 i_s}{R_3 + h_{ie}} = \frac{10 i_s}{10 + 1.5} = 0.87 i_s$$

$$i_3 + i_b(1 + h_{fe}) = (1 - k) i_s + k(1 + h_{fe}) i_s$$

$$A_i = \frac{i_3 + i_b}{i_s} = (1 - 0.87) + 0.87(1 + 50) = 44.4$$

$$v_o = R_E' A_i i_s \quad \text{and} \quad i_s = \frac{v_s}{[R_s + R_3 \| h_{ie} + R_E' A_i]}$$

$$A_v = \frac{v_o}{v_s} = \frac{R_E' A_i}{R_s + R_3 \| h_{ie} + R_E' A_i} = \frac{72.8}{74.1} = 0.98$$

$$R_i = h_{ie} + (1 + h_{fe}) R_E' = 1.50 + 51(1.64) = 85.5 \text{ k}\Omega$$

$$R_o = \frac{h_{ie} + R_s}{1 + h_{fe}} = \frac{1500 + 0}{51} = 29.4\ \Omega \quad (\text{For } R_s = 0)$$

5.36

$$h_{Dib} = h_{ib1} + (1 + h_{fb1}) h_{ib2}$$

$$h_{Dfb} = h_{fb1} + (1 + h_{fb1}) h_{fb2}$$

Also, we have

$$\alpha_D = \alpha_1 + (1 - \alpha_1)\alpha_2$$

From Table 5.4 for Type 2N525, we get

$$h_{Dib} = 31 + (1 - 0.978)(31) = 31 + 0.68 = 31.68\ \Omega$$

$$h_{Dfb} = -0.978 + (1 - 0.978)(-0.978) = -0.9995$$

5.37 $R_{Di} = h_{Die} + (1 + h_{Dfe}) R_e$

$$h_{Die} = 1400 + (1 + 44)(1400) = 64{,}400\ \Omega$$

$$h_{Dfe} = h_{fe1} + (1 + h_{fe1}) h_{fe2}$$

$$= 44 + (1 + 44)(44) = 2024$$

$$R_{Di} = 64.400 + (1 + 2024)(2) = 4114\ k\Omega$$

5.38 $I_B = I_i - I_o$

(a)

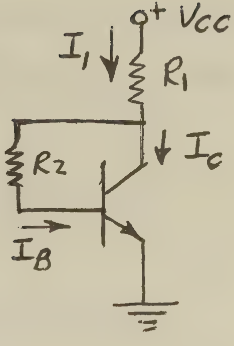
$$I_c = (\beta_N + 1) I_{co} + \beta_N I_B$$

$$= (\beta_N + 1) I_{co} - \beta_N I_o + \beta_N I_i$$

(b) $(\beta_N + 1) I_{co} = \beta_N I_o$ and $I_{co} \doteq I_o$

(c) d-c power loss is less, and em. res. R_e is eliminated.

5.39



(a) $V_{CC}-V_{BE}=(R_1+R_2)I_B+R_1 I_C$

$$I_C=(\beta_N+1)I_{CO}+\beta_N I_B$$

Solving these two equations for I_C, we obtain

$$I_C=\frac{\beta_N(V_{CC}-V_{BE})+(R_1+R_2)(\beta_N+1)I_{CO}}{R_2+(\beta_N+1)R_1}$$

(b)

$$S_I=\left.\frac{\partial I_C}{\partial I_{CO}}\right|_{\beta_N,V_{BE}}=\frac{(R_1+R_2)(\beta_N+1)}{R_2+(\beta_N+1)R_1}$$

(c)

$$S_V=\left.\frac{\partial I_C}{\partial V_{BE}}\right|_{\substack{I_{CO}\\ \beta_N}}=\frac{-\beta_N}{R_2+(\beta_N+1)R_1}$$

$$S_\beta=\left.\frac{\partial I_C}{\partial \beta_N}\right|_{\substack{I_{CO}\\ V_{BE}}}=\frac{[(V_{CC}-V_{BE})+(R_1+R_2)I_{CO}]-R_1 I_C}{R_2+(\beta_N+1)R_1}$$

Assuming $\beta_N+1 \doteq \beta_N$, we have

$$S_\beta \doteq \frac{I_C}{\beta_N}-\frac{R_1 I_C}{R_2+(\beta_N+1)R_1}=\frac{(R_1+R_2)I_C}{\beta_N[R_2+(\beta_N+1)R_1]}$$

NOTE the similiarity between these equations and those in Problems 5.30 and 5.31.

5.40 Correction: Change Fig P5.11 to Fig 5.39.

(a) $$I_c = \frac{80(15-0.20)+(3+60)(80+1)(0.002)}{60+(80+1)(3)} = 3.94\ \text{m}$$

$$I_B = \frac{I_C-(\beta_N+1)I_{CO}}{\beta_N} = \frac{3.94-81(0.002)}{80} = 0.0472\ \text{ma}$$

$$V_{CE} = 15-3(3.94+0.0472) = 3.04\ \text{V}$$

(b) $$S_I = \frac{(R_1+R_2)(\beta_N+1)}{R_2+(\beta_N+1)R_1} = \frac{(3+60)(80+1)}{60+(80+1)(3)} = 16.85$$

$$\frac{S_I}{\beta_N} = \frac{16.85}{80} = 0.21$$

CHAPTER 6

6.1

$$i_b = 0.012(50+20\times 2)^{3/2} = 10.22\ \text{ma} \quad (10.50\ \text{ma})$$

$$i_b = 0.012(25+20\times 4)^{3/2} = 12.9\ \text{"} \quad (10.0\ \text{ma})$$

$$i_b = 0.012(100+0)^{3/2} = 12.0\ \text{"} \quad (12.0\ \text{ma})$$

Curve values shown in parenthesis.

The equation is not accurate for $e_c > 0$, i.e., the positive grid region.

6.2

(a) From Eq (6.36) & Eq (6.40)

$$A_v = \frac{de_b}{de_{cc}} = \frac{-\mu R_b r_g}{(r_g + R_c)(r_p + R_b)}$$

$$A_v = \frac{de_b}{de_{cc}} = \frac{-\mu R_b}{r_p + R_b}$$

(b) $$A_v = \frac{-17.3(1.4)(20)}{(1.4+10)(8.9+20)} = -1.47$$

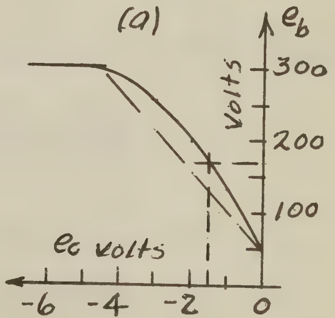
$$A_v = \frac{-17.3(20)}{8.9+20} = -12.0$$

(c) $$A_v = \frac{-17.3(1.4)(20)}{(1.4+1000)(8.9+20)} = -0.0168$$

Severe clipping occurs if $R_c >> r_g$

6.3

(a)



(b) $\mu = 94$, $r_p = 81.6\ k\Omega$
$g_m = 1140\ \mu\mho$

(c) $$A_v = \frac{-94(200)}{81.6+200} = -66.7$$

$$\text{slope} = \frac{300-60}{-3.5} = -68.5$$

(d) $$R_K = \frac{1.5}{0.68} = 2.20\ K\Omega$$

(e) Data for bias line →

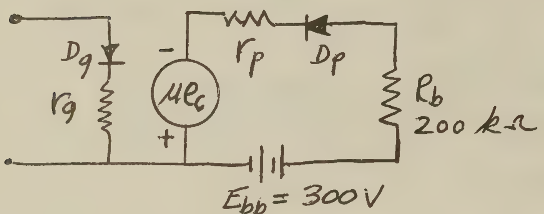
e_K	R_K	i_b (ma)
0.5	220	0.227
1.0	"	0.455
1.5	"	0.68
2.0	"	0.91

6.4 (a) For $e_c = 0$: $i_b = 1.24$ ma, $e_b = 54$ V

$$e_b = r_p i_b - \mu e_c \text{, and } r_p = \frac{54}{1.24} = 43.5\ k\Omega$$

For $e_c = -3.5$: $i_b = 0.08$, $e_b = 282$ V

$$\mu = \frac{282 - 43.5(0.08)}{3.5} = 70.7$$



BP of D_p:

$$e_c = \frac{-300}{70.7} = -4.25$$

$$e_b = 300\text{ V}$$

BP of D_g: $i_b = \dfrac{300}{243.5} = 1.235$ ma & $e_b = 53$ V

(b) The e_b vs e_c characteristic is shown in Prob 6.3(a) by the dashed line. A bettor approximation is obtained by increasing μ so BP of D_p occurs at lower value of e_c.

6.5 At $i_b = 1$ ma, $e_b = 236$ V, and $e_c = -2$ V

$$\mu = \frac{286 - 186}{2.5 - 1.5} = 100$$

$$E_o = e_b + \mu e_c - r_p i_b = 164 + 100(-2) = -36\text{ V}$$

$$r_p = \frac{346 - 164}{2.5\text{ ma}} = 73\ k\Omega \quad \left(\begin{array}{l}\text{evaluated from}\\ \text{slope of } -2\text{V}\\ \text{curve}\end{array}\right)$$

$$g_m = \frac{(1.9 - 0.46)10^{-3}}{2.5 - 1.5} = 1440\ \mu\mho$$

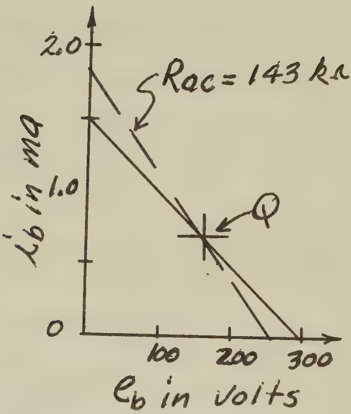
$$g_m = \frac{\mu}{r_p} = \frac{100}{73 \times 10^{+3}} = 1370\ \mu\mho$$

6.6 $X_{cK} \leq \frac{R_K}{10} = \frac{2200}{10} = 220\ \Omega$

$$C_K \geqslant \frac{10}{\omega R_K} = \frac{10}{2\pi(20)(2200)} = 36\ \mu f$$

6.7

(a) $R_{ac} = R_b \| R_{g2} = 143\ k\Omega$



$i_b(max) = 1.38$ ma

$i_b(min) = 0.14$ ma

$I_b = 0.68$ ma

$I_{p1m} = \frac{1.38 - 0.14}{2} = 0.62$ ma

$E_{p1m} = R_{ac} I_{p1m} = 88.7$ V

(b) $X_C = \frac{10^6}{2\pi(1000)(0.02)} = 7950\ \Omega$

Yes, because $7950 \ll 500{,}000\ \Omega$, i.e., $X_C \ll R_{g2}$.

(c)

$$A_v = \frac{e_b(max) - e_b(min)}{e_c(max) - e_c(min)} = \frac{240 - 64}{-3 - 0} = -59$$

$$A_v = \frac{-\mu R_{ac}}{r_p + R_{ac}} = \frac{-94(143)}{82 + 143} = -59.5$$

(d) $I_{p2m} = \frac{1.38 + 0.14 - 2 \times 0.68}{4} = 0.04$ ma

$E_{p2m} = R_{ac} I_{p2m} = 143 \times 0.04 = 5.72$ V

(e) I_b (without signal) $= 0.68$ ma

I_b (with signal) $= 0.68 + 0.04 = 0.72$ ma

6.8 (a)

Load	P_{out}	% 2nd
1500 Ω	2.50 W	15
2000 Ω	2.75 W	12
3000 Ω	2.36 W	5.6
4000 Ω	1.92 W	4.8

(b) Note that severe bottom clipping occur for $R_{load} < 2000\ \Omega$.

(c) $R_K = \dfrac{E_{cc}}{I_b} = \dfrac{40}{40} = 1\ K\Omega$

6.9 (a) $E_{bb} = e_L + e_b$

$e_b(min) = E_{bb} - e_L(max) = 300 - 260 = 40$

From load line : $R_K = R_K' + R_K'' = \dfrac{300}{1.15} = 261\ k$

(b) $e_i = e_c + e_L$; at $e_c = 0$, $e_i(max) = e_L(max) = 2$

(c) cutoff occurs at $e_c \doteq -4.5\ V$ and $e_b = 3$

$e_i(cutoff) = e_c(cutoff) = -4.5\ V$

(d) $E_b = E_{bb} - E_L = 300 - \dfrac{260}{2} = 170\ V$

From load line at $E_b = 170\ V$:

$E_c \doteq -1.75\ V$; $I_b = 0.50\ ma$

$R_K'' = \dfrac{-E_c}{I_b} = \dfrac{1.75}{0.50} = 3.50\ k\Omega$

$R_K' = 261 - 3.50 = 257.5\ k\Omega$

$R_{in} \doteq R_g\left[1 + \dfrac{R_K'}{R_K''}\right] = R_g[1 + 73.5] = 75\ M\Omega$

6.9 (concl.)

$$R_{out} = \frac{r_p}{\mu+1} \doteq \frac{r_p}{\mu} = \frac{72}{100} = 0.720\ k\Omega$$

6.10 (a) From the i_c and i_b loop equations, we obtain

$$i_c = \frac{(R_b+R_K+r_p)e_i - R_K E_{bb}}{\Delta}$$

$$i_b = \frac{(\mu r_g - R_K)e_i + (R_c+R_K+r_g)E_{bb}}{\Delta}$$

$$\Delta = (R_b+R_K+r_p)(R_c+r_g) + (R_b+\mu r_g+r_p)R_K$$

(b) Assuming $e<0$, then $r_g=\infty$, and we have

$$i_c = 0 \quad \text{and} \quad i_b = \frac{\mu e_i + E_{bb}}{R_b+r_p+(\mu+1)R_K}$$

(c) The right hand circuit of Fig P6.10 (b) is derived from the above expression for i_b. Rearranging this expression into the following form

$$i_b = \frac{\frac{\mu e_i}{\mu+1} + \frac{E_{bb}}{\mu+1}}{\frac{R_b+r_p}{\mu+1} + R_K}$$

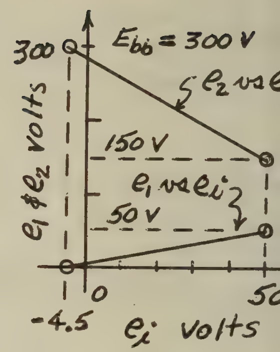
we get the left-hand circuit of Fig P6.10 (b).

(d)

$$A_{v1} = \frac{de_1}{de_i} = \frac{\mu R_K}{r_p+R_b+(\mu+1)R_K}$$

$$A_{v2} = \frac{de_2}{de_i} = \frac{-\mu R_b}{r_p+R_b+(\mu+1)R_K}$$

6.11 A conenient method is to assume values of e_c and the compute e_i.



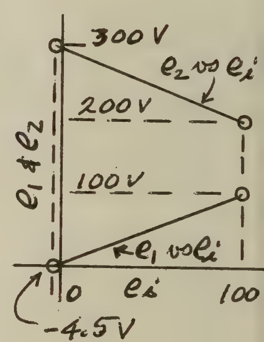
e_c	i_b	e_1	e_2	e_i
0	2.0	50	150	50
-4.5	0	0	300	-4.5

(b) $$\text{Slope } e_2 \text{ vs } e_i = \frac{-(300-150)}{50+4.5} = -2.75$$

$$\text{Slope } e_1 \text{ vs } e_i = \frac{50}{54.5} = 0.918$$

$$A_{v1} = \frac{95 \times 25}{80+75+(96)(25)} = 0.931$$

$$A_{v2} = \frac{-95 \times 75}{80+75+(96)(25)} = -2.79$$



(c) For $R_b = R_K = 50\ K\Omega$

$$\text{Slope } e_2 \text{ vs } e_i = \frac{-100}{104.5} = -0.957$$

$$\text{Slope } e_1 \text{ vs } e_i = \frac{+100}{104.5} = 0.957$$

$$A_{v1} = -A_{v2} = \frac{95 \times 50}{80+50+96(50)} = 0.965$$

6.12 Let us try to obtain a value of I_b of approximately 0.50 ma. A d-c load line of $R_b + R_K = 167$ kΩ intersects the $e_c = -1.5$ V curve at $I_b = 0.57$ ma. Let us use a Q point of

$$I_b = 0.57 \text{ ma}, \quad E_c = -1.5 \text{ V}, \quad E_b = 154 \text{ V}$$

$$R_k = \frac{-E_c}{I_b} = \frac{1.50}{0.57} = 2.63 \text{ k}\Omega$$

$$R_b = 167 - 2.63 \doteq 164 \text{ k}\Omega$$

$$R_{ac} = R_b \| R_g = \frac{164 \times 1000}{1164} = 141 \text{ k}\Omega$$

For $e_c = -1.0$ V, $e_{b(min)} = 125$ V

" $e_c = -2.0$ V, $e_b(max) = 182$ V

$$E_{p1m} = E_{om} = \frac{182 - 125}{2} = 28.5 \text{ V}$$

$$E_{p2m} = \frac{182 + 125 - 2(154)}{4} = -0.25 \text{ V}$$

$$\% \, 2^{nd} = \frac{0.25 \times 100}{28.5} = 0.87 \%$$

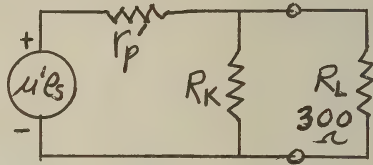
A coupling capacitance $C_c = 0.002 \, \mu f$ has a reactance of

$$X_c = \frac{1}{6000\pi \times 0.002 \times 10^{-6}} = 26{,}500 \, \Omega$$

So a value $C_c \geq 0.002 \, \mu f$ can be used.

6.13 Use a cathode follower circuit. Using the Thévenin model shown in Fig 6.27(b), we obtain

$$R_{out} = R_L = \frac{r_p' R_K}{r_p' + R_K}$$



$$r_p' = \frac{50}{70+1} = 0.704 \text{ k}\Omega$$

$$R_K = \frac{r_p' R_{out}}{r_p' - R_{out}} = \frac{0.704 \times 0.300}{0.704 - 0.300} = 0.522 \text{ K}\Omega$$

6.14 At the BP of D : $i_D = 0$ and $v_D = 0$, so

(a)
$$e_b = \frac{R_1 E_{bb}}{R_1 + R_2} = \frac{600 \times 300}{600 + 200} = 225 \text{ V}$$

$$i_b = \frac{E_{bb} - e_b}{R_b} = \frac{300 - 225}{125} = 0.60 \text{ ma}$$

$$e_i = \frac{-[E_{bb} - (R_b + r_p) i_b]}{\mu} = \frac{-[300 - 120]}{90} = -2 \text{ V}$$

(b) Conducting case:

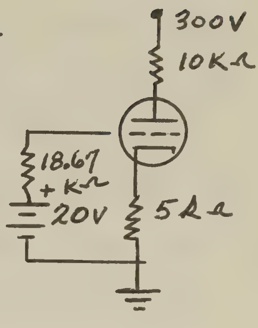
$$A_v = \frac{-\mu R_{eq}}{r_p + R_{eq}} \; ; \; R_{eq} = R_b \| R_2 \| R_1 = 68.2 \text{ k}\Omega$$

$$A_v = \frac{-90 \times 68.2}{75 + 68.2} = -43$$

Nonconducting case:

$$A_v = \frac{-90 \times 125}{75 + 125} = -56.2$$

6.15 Correction: Add $R_K = 5\,k\Omega$



For $e_c < 0$, $i_c = 0$, and

$$i_b = \frac{E_{cc} - e_c}{R_K} = \frac{20 - e_c}{5}$$

where $E_{cc} = \dfrac{R_1 E_{bb}}{R_1 + R_2} = 20\,V$

Bias line and load line intersect at

$$E_c = -9\,V, \quad I_b = 5.8\,ma, \quad E_b = 213\,V$$

6.16 For $e_c \leq 0$, Eq (6.130) gives

(a)
$$E_L = R_K I_b = \frac{R_K[\mu E_i + E_{bb}]}{r_p + (\mu+1)R_K}$$

(b) For $e_c = 0$ and $I_L = 0$, E_L is

$$E_L = \frac{R_K(E_{bb} + \mu e_c)}{r_p + R_K} = \frac{100 \times 300}{8 + 100} = 278\,V$$

(c) For $E_L = 250\,V$ and $I_L = 0$, E_i is

$$E_i = \frac{[8 + 21(100)](250) - 100(300)}{20 \times 100} = 247.5\,V$$

(d) For $R_L = 100\,k\Omega$: $E_L = 248\,V$ & $I_L = 2.48\,ma$

" $R_L = 50\,k\Omega$: $E_L = 247\,V$ & $I_L = 4.94\,ma$

(e) $R_{out} = r_p' \| R_2 = \dfrac{8}{20+1} \| 100 = 0.380\,k\Omega$

6.16 (Concl.)

(f) Yes, by using a tube having a larger g_m. This reduces the value of R_{out}.

(g) If E_{bb} decreases by 10%, E_i decreases by 10%. The 10% drops in E_{bb} and E_i produce a 10% decrease in E_L.

6.17 Correction: Change R_L from 20 kΩ to 100 kΩ

$$E_L = \frac{100\|100[270 + 20(247.5)]}{8 + 21(50)} \doteq 247 \text{ V}$$

NOTE: If $E_L < E_i$, $e_c > 0$ and grid current I_c flows. The large value of $R_g = 200$ kΩ, however, keeps e_c from becoming too large. Assuming $e_c \doteq 0$, the value of E_L for $R_L = 100$ k is

$$E_L = \frac{R_K(E_{bb} + \mu e_c)}{r_p + R_K} = \frac{50(270+0)}{8+50} = 233 \text{ V}$$

Let us use Eq (6.130) and assume $r_g = 1$ kΩ,

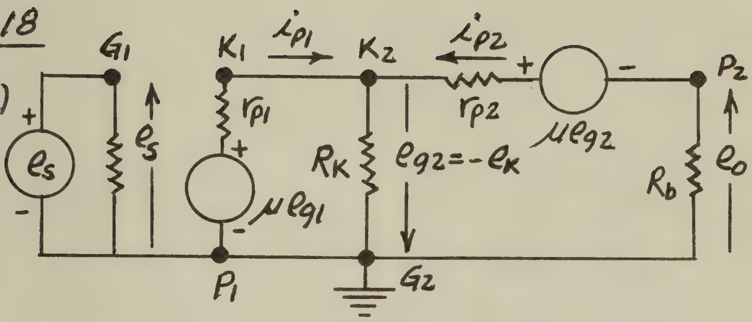
$$E_L = \frac{50[(8+20)(247.5) + (1+200)(270)]}{(8+50)(1+200) + 50(8+20)} = 235 \text{ V}$$

The grid voltage is slightly positive.

$$\% \text{ decrease in } E_L = \frac{248 - 235}{248} = 5.25\,\%$$

6.18

(a)



(b)

$$i_{p2} = \frac{(\mu_2+1)\,e_{g2}}{r_{p2}+R_b} \; ; \; R_{i2} = \frac{e_{g2}}{i_{p2}} = \frac{r_{p2}+R_b}{\mu_2+1}$$

$$i_{p1} = \frac{\mu_1 e_{g1}}{r_{p1}+R_{ki}} = \frac{\mu_1 e_s}{r_{p1}+(\mu_1+1)\,R_{ki}}$$

where $R_{ki} = R_K \| R_{i2}$ and $e_{g1} = e_s - e_K$

$$A_{v1} = \frac{e_K}{e_s} = \frac{\mu_1 R_{ki}}{r_{p1}+(\mu_1+1)R_{ki}}$$

$$A_{v2} = \frac{e_o}{e_K} = \frac{-R_b i_{p2}}{-e_{g2}} = \frac{(\mu_2+1)R_b}{r_{p2}+R_b}$$

(c) $$A_v = \frac{e_o}{e_s} = \frac{e_K}{e_s}\cdot\frac{e_o}{e_K} = A_{v1}A_{v2}$$

$$A_v = \frac{\mu_1(\mu_2+1)R_b R_{ki}}{[r_{p1}+(\mu_1+1)R_{ki}](r_{p2}+R_b)}$$

For identical tubes and $R_K \gg R_{i2}$, we get

$$A_v = \frac{\mu R_b}{2r_p+R_b}$$

6.19 (a) $e_b = (E_{bb} + e_c) - R_b i_b$

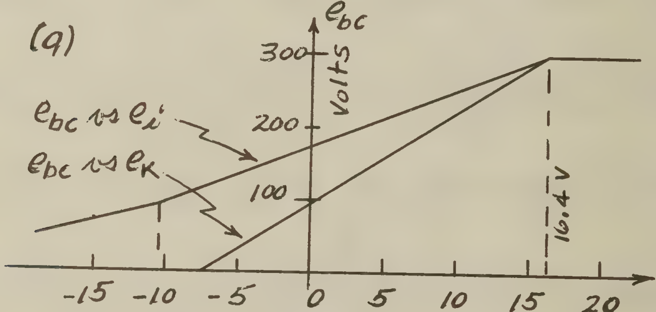
$$= (300 + e_c) - 20 i_b$$

e_c	$E_{bb}+e_c$	i_b	e_b	i_c	i_i	e_i
8	308	14.7	14	5.7	-20.4	-28.4
4	304	13.3	37	2.86	-16.2	-20.2
0	300	10.4	92	0	-10.4	-10.4
-4	296	7.5	148	0	-7.5	-3.5
-8	292	5.0	193	0	-5.0	+3.0
-12	288	3.0	230	0	-3.0	+9.0
-16	284	1.2	257	0	-1.2	+14.8
-20	280	0.20	275	0	-0.2	+19.8

$$e_i = R_K i_i - e_c$$

(b) The path of operation is readily plotted using the above values of e_c, i_b, and e_b. The path is quite linear.

6.20 (a)

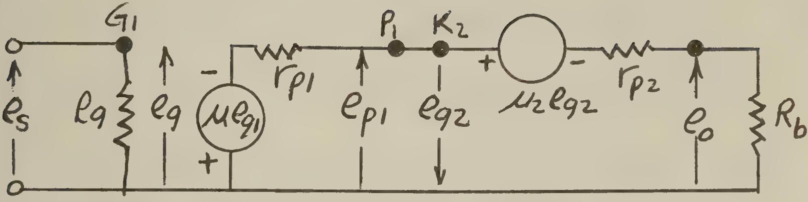


(b)

Slope of e_{bc} vs $e_i = A'_v = 7.76$

" " " " $e_K = A_v = 12.7$

6.21 (a)



Load on T_1 is input to cathode of T_2, i.e.,

(b) $$R_{i2} = \frac{R_b + r_{p2}}{\mu_2 + 1}$$

$$A_{v1} = \frac{e_{p1}}{e_s} = \frac{-\mu_1 R_{i2}}{r_{p1} + R_{i2}} = \frac{-\mu_1 (R_b + r_{p2})}{(\mu_2 + 1) r_{p1} + r_{p2} + R_b}$$

$$e_o = \frac{-(\mu_2 + 1) e_{g2} R_b}{r_{p2} + R_b} = \frac{(\mu_2 + 1) R_b e_{p1}}{r_{p2} + R_b}$$

$$A_{v2} = \frac{(\mu_2 + 1) R_b}{r_{p2} + R_b} = \frac{R_b}{R_{i2}}$$

(c) $$A_v = \frac{e_o}{e_s} = A_{v1} A_{v2} = \frac{-\mu_1 R_b}{r_{p1} + R_{i2}} \doteq -g_{m1} R_b$$

6.22 (a) The model shown in Fig. P6.22b is derived from the Thevenin model of the cathode follower given in Fig. 6.27 (b).

6.22 (Concl.) The loop equations are

(b) $e_{11} = R_{11} i'_{b1} + R_K i'_{b2}$

$e_{22} = R_K i'_{b1} + R_{22} i'_{b2}$

From these equations we obtain

$$i'_{b1} = \frac{R_{22} e_{11} - R_K e_{22}}{R_{11} R_{22} - R_K^2}$$

$$i'_{b2} = \frac{R_{11} e_{22} - R_K e_{11}}{R_{11} R_{22} - R_K^2}$$

where

$$R_{11} = \frac{r_{p1} + R_{b1}}{\mu_1 + 1} + R_K$$

$$R_{22} = \frac{r_{p2} + R_{b2}}{\mu_2 + 1} + R_K$$

$$e_{11} = \frac{\mu_1 e_1 + E_{bb}}{\mu_1 + 1} \quad \text{and} \quad e_{22} = \frac{\mu_2 e_2 + E_{bb}}{\mu_2 + 1}$$

(c) $e_o = -R_b(i'_{b1} - i'_{b2}) = \dfrac{-\mu R_b (e_1 - e_2)}{r_p + R_b}$

(d) $R_{11} = R_{22} = 2.86\ k\Omega$

$e_{11} = \dfrac{20(2)+300}{21} = 16.2\ V$, $e_{22} = \dfrac{0+300}{21} = 14.3\ V$

$i'_{b1} = 4.25\ ma$, $i'_{b2} = 2.03\ ma$

$e_o = -10(4.25-2.03) = -22.2\ V$, $A_v = \dfrac{-22.2}{2} = 11.1$

CHAPTER 7

7.1 (a) $i_{b1} = k\left[e_b + \mu_1 e_{c1} + 150\mu_2\right]^{3/2}$

For $e_{c2} = 100$ V,

$$i_{b2} = \left(\frac{100}{150}\right)^{3/2} i_{b1} = k\left[(e_b + \mu_1 e_{c1})\left(\frac{100}{150}\right) + 100\mu_2\right]^{3/2}$$

b) In Fig 7.6 multiply each voltage scale by (100/150) and the plate current scale by $(100/150)^{3/2} = 0.545$. Doing this, we get for

$$e_{c2} = 100\text{ V},\ e_b = 200\text{ V},\ e_{c1} = -2\text{ V},\ e_{c3} = 0\text{ V}$$

a plate current i'_{b2} of

$$i'_{b2} = 0.545(2.50) = 1.36 \text{ ma}$$

7.2 (a) $i_b = f_1(e_b, e_{c1}, e_{c2})$

$$i_p = di_b = \left(\frac{\partial i_b}{\partial e_b}\right) de_b + \left(\frac{\partial i_b}{\partial e_{c1}}\right) de_{c1} + \left(\frac{\partial i_b}{\partial e_{c2}}\right) de_{c2}$$

$$i_p = g_p e_p + g_{p1} e_{g1} + g_{p2} e_{g2}$$

In a similiar manner, we obtain

$$i_{g1} = di_{c1} = g_{1p} e_p + g_{11} e_{g1} + g_{12} e_{g2}$$

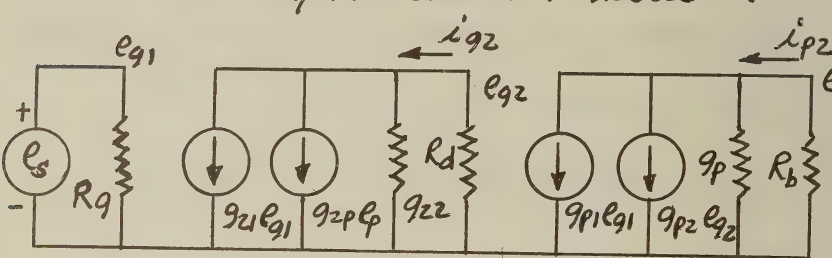
$$i_{g2} = di_{c2} = g_{2p} e_p + g_{21} e_{g1} + g_{22} e_{g2}$$

Where the g's are conductances defined by the partial derivatives

$$g_{1p} = \left(\frac{\partial i_{c1}}{\partial e_b}\right), \quad g_{11} = \left(\frac{\partial i_{c1}}{\partial e_{c1}}\right), \quad g_{12} = \left(\frac{\partial i_{c1}}{\partial e_{c2}}\right)$$

$$g_{2p} = \left(\frac{\partial i_{c2}}{\partial e_b}\right), \quad g_{21} = \left(\frac{\partial i_{c2}}{\partial e_{c1}}\right), \quad g_{22} = \left(\frac{\partial i_{c2}}{\partial e_{c2}}\right)$$

(b) Using the above expressions and assuming $e_{c1} < 0$, we can construct the following incremental model:



(c)
$$k = \frac{i_{g2}}{i_p} \; ; \; e_{g2} = -R_d i_{g2} = -R_d k i_p$$

$$g_{p2} e_{g2} = -g_{p2} k R_d i_p$$

Making the above substitution for $g_{p2} e_{g2}$, we get the model shown in Fig P7.2c.

$$A_v = \frac{e_p}{e_{g1}} = \frac{-g_{p1} R_b}{1 + g_p R_b + k g_{p2} R_d}$$

(d) R_d causes screen degeneration and it reduces the gain A_v. It should be bypassed with a large capacitor.

7.3 Select a Q-point in the center of the linear region. One possible set of quiescent values is

$$E_b = 250\ V,\ E_c = -10\ V,\ \text{and}\ I_b = 105\ ma$$

An a-c plate load $R_L = 4000\ \Omega$ intersects the $e_c = 0$ curve just above the knee. For a grid swing of 10 volts about $E_c = -10\ V$, we get the following data:

$$e_c = 0,\ i_b(max) = 160\ ma$$

$$e_c = -20,\ i_b(min) = 50\ ma.$$

$$I_{p1m} = \frac{160-50}{2} = 55\ ma$$

$$I_{p2m} = \frac{160+50-2(105)}{4} = 0$$

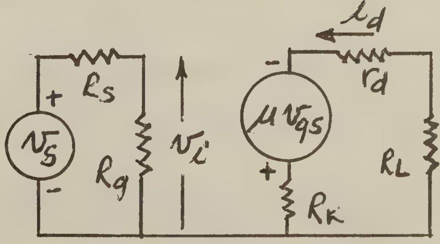
$$P_{OUT} = \frac{(0.055)^2(4000)}{2} = 6.0\ \text{watts}$$

$$R_K = \frac{10}{0.105} = 95\ \Omega$$

$$I_{p3m} = \frac{(160-50)-2(130-70)}{6} = -1.67\ ma$$

$$\%\ 3^d = \frac{1.67 \times 100}{55} = 3$$

.4 (a)



$$i_d = \frac{\mu(v_i - R_K i_d)}{r_d + R_L + R_K}$$

$$v_o = -R_L i_d$$

$\mu = g_m r_d$

7.4 (concl.)

$$A_{vr} = \frac{v_o}{v_s} \doteq \frac{-\mu R_L}{r_d + R_L + (\mu+1)R_K} \qquad \text{For } R_g \gg R_s$$

(b) For the Type 40461

$g_{fs} = 3500\ \mu\mho$, $r_d = 13{,}000\ \Omega$

$\mu = 3500 \times 10^{-6} \times 13{,}000 = 45.50$

R_K bypassed:

$$A_{vr} = \frac{-45.50 \times 2}{13+2} = -6.06$$

C_K omitted:

$$A_{vr} = \frac{-45.50 \times 2}{13 + 2 + 23.3} = -2.37$$

7.5 One possibility is to select the bias point at

$V_{GS} = -2\,V$, $I_D = 4.5\ ma$, $V_{DS} = 12\,V$

$R_{dc} = R_L + R_K = \frac{24}{9} = 2.67\ k\Omega$

$R_K = \frac{2.0}{4.5} = 0.445\ k\Omega$ & $R_L = 2.225\ k\Omega$

$v_{DS} = 0$, $i_D'(max) = 8.0\ ma$

$v_{DS} = -4$, $i_D'(min) = 1.0\ ma$

$I_{d1m} = \frac{8-1}{2} = 3.5\ ma$, $I_{d2m} = \frac{8+1-2(4.5)}{4} = 0$

7.5 (Concl.)

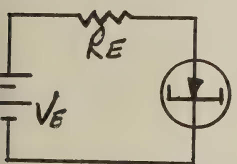
$$V_{om} = R_L I_{d1m} = 2.225 \times 3.5 = 7.8\,V$$

$$I_{d3m} = \frac{(8-1) - 2(6.5-2.5)}{6} = 0.167\ ma$$

$$\%\ 3^{d} = \frac{0.167 \times 100}{3.5} = 4.8\%$$

7.6 The voltage v_{EB1} increases exponentially in the high resistance Cutoff Region as shown in Fig P7.6 until $v_{EB1} = V_p$; then v_{EB1} decreases rapidly as the operation enters the low resistance Negative Resistance Region to a value of V_{min}. The cycle now repeats. The capacitance C affects the charging and discharging time constants of the circuit. Reducing C increases the frequency of oscillation.

7.7 (a) The Thévenin equivalent bias circuit is



For single intersection,

$$R_E = \frac{R_S R_L}{R_S + R_L} < |r_d|$$

$$V_E = \frac{R_L V_{DD}}{R_S + R_L} < 150\ mV$$

$$V_{DD} = \frac{120 \times 150}{120 + 120} = 300\ mV$$

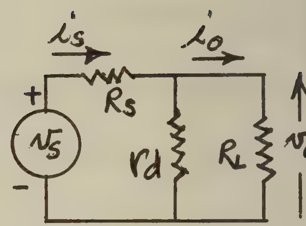
$$r_d = \frac{-(150-25)}{2-0.20}$$

$$r_d = -69.5\,\Omega$$

$$R_S = R_L = 120\,\Omega$$

$$R_E = 60\,\Omega$$

7.7 (Concl.) (b) & (c)



$$i_s = \frac{(r_d + R_L)\, v_s}{R_L R_s + r_d (R_s + R_L)}$$

$$A_i = \frac{i_o}{i_s} = \frac{r_d}{r_d + R_L}$$

$$v_o = R_L i_o = \frac{R_L r_d i_s}{r_d + R_L} = \frac{R_L r_d v_s}{R_L R_s + r_d (R_s + R_L)}$$

$$A_v = \frac{v_o}{v_s} = \frac{R_L r_d}{R_L R_s + r_d (R_L + R_s)}$$

$$G_i = \frac{P_o}{P_o'} = \frac{R_L i_o^2}{\left(\frac{v_s}{R_s + R_L}\right)^2 R_L} = \frac{R_L A_i^2 i_s^2}{\left(\frac{v_s}{R_s + R_L}\right)^2 R_L}$$

$$G_i = \frac{r_d^2 (R_s + R_L)^2}{[R_L R_s + r_d (R_L + R_s)]^2} = \frac{r_d^2}{[R_E + r_d]^2}$$

$$R_E = R_L \| R_s = \frac{R_L R_s}{R_L + R_s}$$

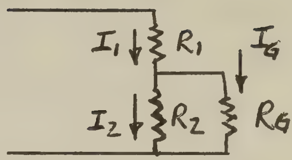
Yes, when $R_E = |r_d|$ denominator goes to zero and $G_i \to \infty$.

(d)
$$G_i = \frac{(-69.5)^2}{(60 - 69.5)^2} = 53.5$$

7.8 (a) $V_i(\text{rms}) = \frac{165}{2} = 82.5$ (for $\theta_c = 180°$)

$$R_L = \frac{V_i(\text{rms})}{I_L(\text{rms})} = \frac{82.5}{0.50} = 165\ \Omega$$

7.8 (Concl.) (b) $I_G = 2.0$ ma



$R_{G2} = R_2 \| R_G$

$$v_G(30^\circ) = 0.70 = \frac{R_{G2}(165 \sin 30^\circ)}{R_1 + R_{G2}}$$

$$\frac{R_{G2}}{R_1 + R_{G2}} = \frac{0.70}{82.5} = 0.00847$$

$$I_1 = I_G + I_2 = 2 + I_2$$

If $I_2 = 0$: $I_1 = I_G = 2.0$ ma & $R_1 = 40.9$ k-Ω

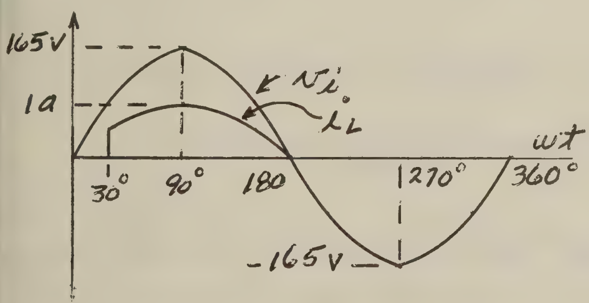
If $I_2 = I_G = 2.0$ ma: $R_1 = 20.45$ k-Ω

and $R_2 = R_G = \dfrac{0.70}{2} = 0.350$ k-Ω

(c) $$I_{ave} = \frac{1}{2\pi}\int_{30^\circ}^{180^\circ} I_{Lm} \sin \omega t \, d(\omega t)$$

$$= \frac{1.866 \, I_{Lm}}{2\pi} = 0.297 \, I_{Lm}$$

$$= 0.297(1) = 0.297 \text{ a}$$



<u>7.9</u> (a) Use the circuit of Fig P7.8 and let R_L represent the hot plate.

(b)

$$V_{im} = 230\sqrt{2} = 325 \text{ V}$$

$$V_{rms} = \frac{V_{im}}{2} = \frac{325}{2} = 162.5 \text{ V} \quad (\text{for } \theta_c = 180^\circ)$$

$$P = \frac{V_{rms}^2}{R_L} \quad \text{so} \quad R_L = \frac{(162.5)^2}{1500} = 17.6\ \Omega$$

$$I_{L(rms)} = \frac{1500}{162.5} = 9.23 \text{ a} \quad (\text{for } \theta_c = 180^\circ)$$

(c)
$$V_{rms} = \left[\int_{90^\circ}^{180^\circ} \frac{(V_{im} \sin \omega t)^2}{2\pi} d(\omega t)\right]^{1/2}$$

$$= \frac{V_{im}}{2\sqrt{2}} = \frac{325}{2\sqrt{2}}$$

$$P(\theta_c = 90^\circ) = \left(\frac{325}{2\sqrt{2}}\right)^2 \frac{1}{17.6} = 750 \text{ w}$$

<u>7.10</u> (a)

(1) Circuit Fig P7.10(a) provides zero bias

$$R_d = \frac{V_{DD} - V_{DS}}{I_D} = \frac{20 - 10}{9 \times 10^{-3}} = 1100\ \Omega$$

(2) Circuit Fig P7.10(c) provides positive bias.

$$V_{GS} = \frac{R_1 V_{DD}}{R_1 + R_2} \quad \text{or} \quad \frac{R_1}{R_1 + R_2} = \frac{V_{GS}}{V_{DD}} = \frac{2}{20} = \frac{1}{10}$$

$R_1 = 1\ M\Omega$ & $R_2 = 9\ M\Omega$ is a possible combination.

7.10 (Concl.)

$$R_d = \frac{20-10}{15\times10^{-3}} = 667\,\Omega$$

(3) circuit Fig P7.10 (b) provides negative bias.

$$R_K = \frac{V_{GS}}{I_D} = \frac{2}{4.5\times10^{-3}} = 445\,\Omega$$

$$R_d = \frac{20-10-2}{4.5\times10^{-3}} = 1780\,\Omega$$

(b) The circuit of Fig P7.10(d) combines the circuits of Figs P7.10 (b) and (c). The negative voltage developed across R_K can be played against the positive voltage across R_1 to provide either a negative or a positive bias.

CHAPTER 8

8.1

$$I_C = -\alpha_N I_{ES}[\exp(v_{EB}/\phi)-1] + I_{CS}[\exp(v_{CB}/\phi)-1]$$

For $v_{EB} > 4\phi$ and $v_{CB} < 4\phi$,

$$I_C \doteq -\alpha_N I_{ES} \exp(v_{EB}/\phi) - I_{CS}$$

$$I_C \doteq -\alpha_N I_{ES} \exp(v_{EB}/\phi)$$

8.1 (Concl.)

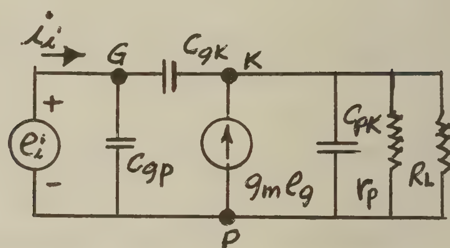
$$g_m = \frac{\partial I_C}{\partial v_{EB}} = \frac{-\alpha_N I_{ES}}{\phi} \exp(v_{EB}/\phi)$$

$$g_m = \frac{|I_C|}{\phi} = \frac{|I_C| e}{kT}$$

8.2

Let

$$A_{gK} = \frac{e_L}{e_i}$$



$$i_i = j\omega C_{gp} e_i + j\omega C_{gK}(e_i - e_L)$$

$$i_i = j\omega[C_{gp} + (1-A_{gK})C_{gK}]\, e_i$$

$$C_i = C_{gp} + (1-A_{gK})C_{gK}$$

$$C_i = 1.5 + (1-0.90)(1.6) = 1.5 + 0.16 = 1.66\ pf$$

The Miller effect is seen to be negligible

8.3

$$Z(s) = R + \frac{1}{sC} = 0, \text{ so } \omega_n = \frac{1}{RC}$$

$$Z(s) = R_1 + R_2 + \frac{1}{sC}, \text{ so } \omega_n = \frac{1}{(R_1+R_2)C}$$

$$Y(s) = \frac{1}{R_2} + sC, \text{ so } \omega_n = \frac{1}{R_2 C}$$

8.3 (Concl.)

$$Z(s) = \frac{R_1 R_2}{R_1 + R_2} + sL = 0, \text{ so}$$

$$\omega_n = \frac{R_1 R_2}{(R_1 + R_2)L}$$

8.4 (a) & (b)

	6AK5	6AU6	6DK6	6JD6
$-A_v C_{gp}$	0.32	0.056	0.40	0.304
C_T pf	7.12	10.56	8.60	11.50
$F_T \times 10^6$	705	380	1140	1220

The 6JD6 has the highest C_T.

c) The capacitance C_{gp} has a negligible effect upon the high-frequency performances of these pentodes.

8.5 (a)

$$\omega_2 = \frac{1}{RC_t} = \frac{1}{R(2.8 + 4.0 + 7.0)10^{-12}}$$

$$R = \frac{1}{2\pi \times 5 \times 10^6 \times 13.8 \times 10^{-12}} = 2310\ \Omega$$

$$A_{vr} = -g_m R = -5000 \times 10^{-6} \times 2310 = -11.55$$

$$R_L \doteq R = 2310\ \Omega$$

$$\omega_1 = \frac{1}{(R_{Lp} + R_g)C_c} = \frac{1}{(2310 + 1{,}000{,}000)C_c}$$

8.5 (Concl.)

$$C_c = \frac{1}{2\pi \times 20 \times 1.002 \times 10^6} = 0.00795\ \mu f$$

(b) Yes, by using the 6JD6.

$$C_t = 11.5 + 7 = 18.5\ pf$$

$$R = \frac{2310 \times 13.8}{18.5} = 1725\ \Omega$$

$$A_{vr} = -14{,}000 \times 10^{-6} \times 1725 = -24.1$$

8.6 It is necessary to measure the upper cutoff frequency f_2 and the mid-frequency gain A_{vr}. Suppose the amplifier consists of a single stage using a 6DK6 pentode, and for test purposes let us use an R_b of 2000 Ω. The measured results are:

$$A_{vr} = -19 \quad \text{and} \quad f_2 = 5.56 \times 10^6\ Hz$$

$$\omega_2 = 2\pi f_2 \doteq \frac{1}{R_b C_o} = \frac{1}{R_b (C_{pk} + C_w)}$$

$$C_o = \frac{1}{2\pi \times 5.56 \times 10^6 \times 2000} = 14.3\ pf$$

$$C_w = C_o - C_{pk} = 14.3 - 6.3 = 8\ pf$$

g_m can also be determined:

$$g_m = \frac{-A_{vr}}{R} = \frac{19}{2000} = 9500\ \mu\mho$$

8.7 The input circuit introduces an attenuating factor k and an additional natural frequency ω_s.

$$k = \frac{R_1}{R_1 + R_s} \quad \& \quad \omega_s = \frac{1}{R_1 \| R_s \, C_i}$$

The high frequency gain expression becomes

$$A_{vH}(s) = k A_{vr} \left[\frac{\omega_2}{s+\omega_2} \cdot \frac{\omega_s}{s+\omega_s} \right]$$

$$k A_{vr} = \frac{10^6(-19.7)}{10^6 + 500} \doteq -19.7$$

$$\omega_2 = 9.88 \times 10^6 \text{ radians/sec} \quad (\text{Text pp } 444)$$

$$\omega_s = \frac{1}{10^6 \| 500 \times 10.5 \times 10^{-12}} = 191 \times 10^6 \text{ radians/sec}$$

Since $k \doteq 1$ and $\omega_s \gg \omega_2$, the input circuit has essentially no effect upon the high-frequency performance of the amplifier.

8.8

f	actual	approx	error	f	actual	approx	error
$0.10 f_2$	5.7	0	−5.7	$0.60 f_2$	31	35	+4
0.20 "	11.3	13.5	+2.2	0.70 "	35	38	+3
0.30 "	16.7	21.5	+4.8	0.80 "	38.6	40.5	+1.9
0.40 "	21.8	27	+5.2	0.90 "	42	43	+1
0.50 "	26.5	31	+4.5	1.00 "	45	45	0

8.9 $A_{vr}(db) = 20 \log A_{vr} = 60$

$A_{vr} = 1000$

$$A_v(s) = \frac{1000\, s^2 (s+100)\, 10^5 \cdot 10^6}{(s+10)^2 (s+1000)(s+10^5)(s+10^6)}$$

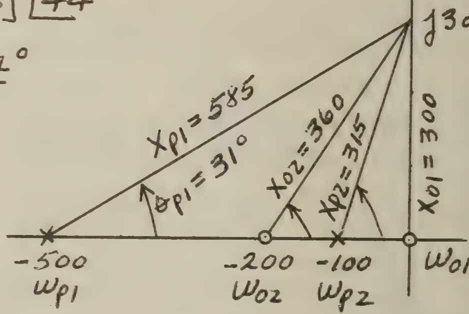
$$A_v(s) = \frac{s^2 (s+100)\, 10^{14}}{(s+10)^2 (s+1000)(s+10^5)(s+10^6)}$$

8.10 (a) For $\omega = 300$ radians/sec we have

$$A_v(j300) = -20\left[\frac{360 \times 300}{585 \times 315}\right] \angle 90+57-31-72$$

$$= -20\,[0.586]\,\angle 44^\circ$$

$$= -11.72\,\angle 44^\circ$$



$\theta_{o2} = 57^\circ$ $\theta_{o1} = 90^\circ$

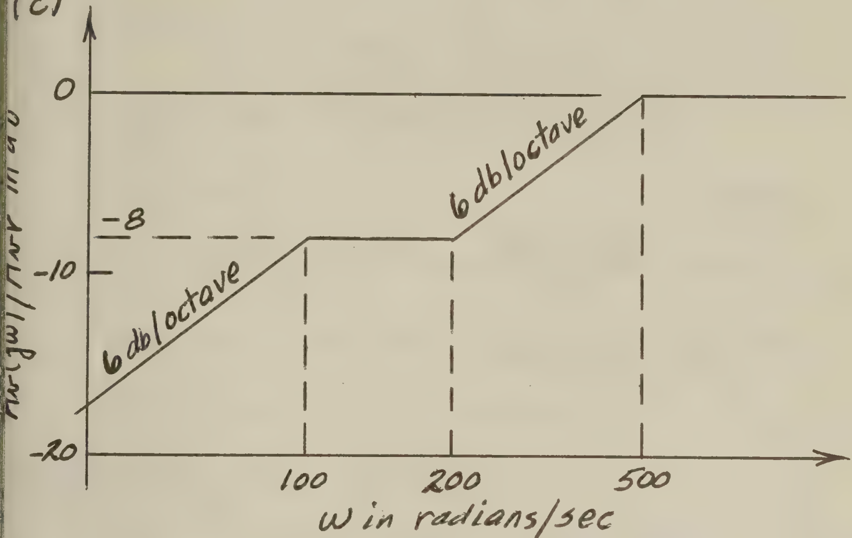
$\theta_{p2} = 72^\circ$

ω	X_{o1}	X_{o2}	X_{p1}	X_{p2}	θ_{o1}	θ_{o2}	θ_{p1}	θ_{p2}	$A_v(j\omega)$
0	0	200	500	100	90	0	0	0	0
100	100	225	510	141	90	27	11	45	$-6.26\angle 6$
300	300	360	585	315	90	57	31	72	$-11.72\angle 44$
500	500	530	700	500	90	68	45	79	$-15.16\angle 3$
1000	1000	1020	1120	1005	90	79	64	85	$-18.20\angle 2$

8.10 (Concl.)

(b) As $\omega \to \infty$, $A_v(j\omega) = -20\angle 0^\circ$

(c)



8.11

The solution of this problem is given in the text on pages 464 to 466.

$$\omega_\pi = \frac{1}{R_{eq} C_{\pi t}} = \frac{1}{373 \times 295 \times 10^{-12}} = 9.1 \times 10^6 \text{ radians/sec}$$

8.12 The nodal equations for Fig P8.12 are:

$$I_n(s) = \frac{V_s(s)}{r_x + R_s} = \left[G_{eq} + s(C_\pi + C_\mu)\right] V_\pi(s) - sC_\mu V_o(s)$$

$$0 = (g_m - sC_\mu) V_\pi(s) + (G_{Lt} + sC_\mu) V_o(s)$$

Solving for $V_o(s)$, we obtain

8.12 (Cont'd)

$$V_o(s) = \frac{\left(s - \frac{g_m}{C_\mu}\right) V_s(s)}{C_\pi (R_s + r_x)\left[s^2 + bs + c\right]}$$

$$= \frac{\left(s - \frac{g_m}{C_\mu}\right) V_s(s)}{C_\pi (R_s + r_x)(s + \omega_A)(s + \omega_B)}$$

where

$$b = \frac{G_{eq} + g_m}{C_\pi} + \frac{(G_\pi + C_\mu) G_{LO}}{C_\pi C_\mu}$$

$$c = \frac{G_{eq} G_{LO}}{C_\pi C_\mu}$$

$$b = \omega_A + \omega_B \doteq \omega_A \quad (\text{For } \omega_A \gg \omega_B)$$

$$c = \omega_A \omega_B \quad \& \quad \omega_B = \frac{c}{\omega_A} = \frac{c}{b}$$

$$\omega_B = \frac{c}{b} = \frac{G_{eq} G_L}{G_{eq} C_\mu + (C_\pi + C_\mu) G_L + g_m C_\mu}$$

$$= \frac{1}{R_{eq}\left[C_\pi + (1 + g_m R_{LO}) C_\mu + \frac{R_{LO} C_\mu}{R_{eq}}\right]}$$

$$\omega_A = \frac{c}{\omega_B} = \frac{1}{\omega_B R_{eq} R_{LO} C_\pi C_\mu}$$

$$\omega_B = \frac{1}{R_{eq}\left[100 + 195 + 13.4\right] 10^{-12}} = \frac{295\ \omega_\pi}{308.4}$$

8.12 (Concl.)

$$\omega_B = 0.957\,\omega_\pi = 8.7 \times 10^6 \text{ radians/sec}$$

$$\omega_A = \frac{1}{8.7\times10^6 \times 373 \times 1000 \times 100 \times 5 \times 10^{-24}}$$

$$\omega_A = 615 \times 10^6 \text{ radians/sec}$$

so $\omega_A \gg \omega_B$

ω_π is 4.35 % high in this instance.

Yes, we are justified in using the Miller equivalent capacitance $C_{\pi t}$.

8.13

(a) The capacitance C_o introduces an additional natural frequency ω_o and the gain expression becomes

$$A_{vH}(s) = A_{vr}\left[\frac{\omega_\pi\,\omega_o}{(s+\omega_\pi)(s+\omega_o)}\right]$$

$$\omega_o = \frac{1}{R_{LO}C_o}\ , \quad R_{LO} = \frac{r_o R_L}{r_o + R_L}$$

(b) $\omega_o = \dfrac{1}{990 \times 100 \times 10^{-12}} = 10.1 \times 10^6 \text{ r/s}$

The Bode plot will have a break at $\omega_\pi = 9.1\times10^6$ r/s with 6 db/octave slope, and a second break at $\omega_o = 10.1\times10^6$ r/s with a 12 db/octave slope.

8.14

$$s^2+bs+c=(s+\omega_d)(s+\omega_m)$$
$$=s^2+(\omega_d+\omega_m)s+\omega_d\omega_m$$

Let $\omega_d=k\omega_m$

$$\omega_d+\frac{\omega_d}{k}=b\ ,\ \omega_d=\frac{b}{1+1/k}\doteq b$$

$$\%\ \text{error}=\frac{\omega_d}{k\omega_d}\times 100=\frac{100}{k}$$

$$\omega_m=\frac{c}{\omega_d}=\frac{c}{b}(1+1/k)\doteq\frac{c}{b}$$

8.15

$$R_e=\frac{4\text{ V}}{4\text{ ma}}=1\text{ K}\Omega\ ,\ g_m=0.0385\times 4=0.1540$$

$$S_I=\frac{(60+1)(1+1/10)}{1+(60+1)(\frac{1}{10})}=9.43$$

$$(C_\pi+C_\mu)=\frac{g_m}{\omega_T}=\frac{0.1540}{100\times 10^6}=1540\text{ pf}$$

$$C_\pi=1540-50=1490\text{ pf}$$

$$r_\pi=\frac{\beta_o}{g_m}=\frac{60}{0.1540}=390\ \Omega$$

$$R_{eq}=.390\,||\,(10||1)=0.273\text{ k}\Omega=273\ \Omega$$

$$R_c=\frac{V_{CC}-R_eI_E-V_{CE}}{I_c}=\frac{12-4-4}{4}=1\text{ K}\Omega$$

$$C_{\pi t}=C_\pi+C_\mu(1+g_mR_{LC})=1490+(1+0.1540\times 500)50$$

$$C_{\pi t}=1490+3900=5390\text{ pf}$$

8.15 (concl.)

$$f_\pi = \frac{\omega_\pi}{2\pi} = \frac{1}{2\pi \times 273 \times 5390 \times 10^{-12}}$$

$$= \frac{0.680 \times 10^6}{2\pi} = 108{,}000\ Hz$$

$$\omega_d = \omega_{ss} + \omega_{es} = 2\pi(50) = 314\ r/s$$

Assume $C_s = 5\ \mu f$

$$\omega_{ss} = \frac{1}{(390+1000) \times 5 \times 10^{-6}} = 144\ r/s$$

$$\omega_{es} = 314 - 144 = 170\ r/s$$

$$C_e = \frac{1+\beta_o}{R_{ss}\,\omega_{es}} = \frac{61}{1390 \times 170} = 258\ \mu f$$

Let us make $\omega_c = \dfrac{1}{(R_c+R_L)C_c} = 2\pi(20)$

$$C_c = \frac{1}{2000 \times 40\pi} = 3.98\ \mu f$$

Use $C_c = 5\ \mu f$

$$V_{BB} = 0.20 + (10+1)\left(\frac{4}{60}\right) + 1(4) = 4.94\ V$$

$$R_2 = \frac{R_b V_{CC}}{V_{BB}} = \frac{10 \times 12}{4.94} = 24.3\ k\Omega$$

$$R_1 = \frac{R_2 R_b}{R_2 - R_b} = \frac{24.3 \times 10}{24.3 - 10} = 17\ k\Omega$$

8.16

$$\alpha_o i_{er} = \alpha i_e \quad \& \quad \alpha = \frac{i_{er}}{i_e}\alpha_o$$

$$i_{er} = \frac{i_e}{r_e C_\pi\left[s + \frac{1}{r_e C_\pi}\right]} = \frac{\omega_\alpha i_e}{s + \omega_\alpha}$$

$$\omega_\alpha = \frac{1}{r_e C_\pi}$$

$$\alpha = \frac{i_{er}}{i_e}\alpha_o = \frac{\omega_\alpha \alpha_o}{s + \omega_\alpha}$$

$$\alpha = \frac{\alpha_o}{1 + j\omega/\omega_\alpha}$$

8.17

(a) $h_{ie} = \frac{7}{1-0.98} = 350\,\Omega$, $\beta_o = \frac{0.98}{1-0.98} = 49$

$$h_{oe} = \frac{10\times10^{-6}}{1-0.98} = 500\times10^{-6}\,\mho$$

$$h_{re} = \frac{7\times10\times10^{-6}}{1-0.98} - 1300\times10^{-6} = 2200\times10^{-6}$$

$g_m = 0.04\times5 = 0.20\,\mho$, $r_\pi = \frac{49}{0.20} = 245\,\Omega$

$$(C_\pi + C_\mu) = \frac{1}{2\pi\times40\times10^6\times245} = 16.3\ pf$$

$$C_\pi = 16.3 - 2 = 14.3\,pf$$

$$r_x = 350 - 245 = 105\,\Omega$$

$$r_\mu = \frac{r_\pi}{h_{re}} = \frac{245}{2200\times10^{-6}} = 0.112\times10^6\,\Omega$$

8.17 (Concl.)

(b)

$$\beta(100\,MHz) = \frac{49}{\left[1+\left(\frac{100}{40}\right)^2\right]^{1/2}} = 18.2$$

$$\omega_T = \frac{g_m}{C_\pi + C_\mu} = \frac{0.20}{16.3\times10^{-12}} = 12.3\times10^9\ r/s$$

8.18

It is suggested that the specifications of the single stage amplifier be so selected that the amplifier can be used directly in the cascaded amplifier design of Problem 9.4. For example select the Type 2N3251 transistor and upper and lower cutoff frequencies of

$$f_2 \geq 1.96\times4.0 = 7.84\ MHz$$

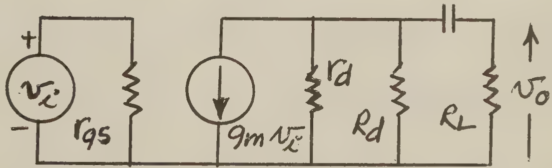
$$f_1 \leq 0.51\times30 = 15.3\ Hz$$

These frequencies are for $n=3$ stages.

8.19 (a)

$v_o = -g_m R v_i$

$R = r_d \| R_d \| R_L$

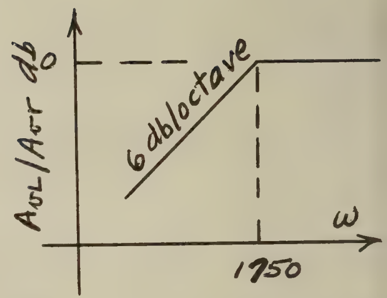


$$A_{vr} = -g_m R = -2000\times10^{-6}\times12.5\times10^3 = -25$$

(b) $$\omega_1 = \frac{1}{(R_d\|r_d + R_L)C_c} = \frac{1}{(14.3+100)10^3\times5\times10^{-9}}$$

8.19 (Concl.)

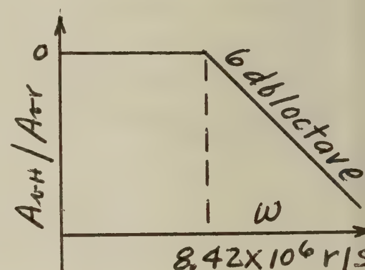
$$\omega_1 = 1750 \text{ r/s}$$



(c) $C_i = C_{gs} + C_{gd}(1 - A_{vr}) = 4 + 3(1+25) = 82 \text{ pf}$

(d) $$\omega_2 = \frac{1}{R(C_{ds}+C_W)} = \frac{1}{12{,}500(3.5+6.0)10^{-12}}$$

$$\omega_2 = 8.42 \times 10^6 \text{ r/s}$$



(e) $$F_T = \frac{g_m}{C_T}$$

$$C_T = C_{gs} + C_{ds} + (1 - A_{vr})C_{gd}$$

$$C_T = [4 + 3.5 + (1+15)(3)]$$

$$F_T = \frac{2000 \times 10^{-6}}{55.5 \times 10^{-12}} = 36.1 \times 10^6 \text{ r/s}$$

8.20 (a) & (b)

	#1	#2	#3	#4
$C_{gs} + (1+15)C_{gd}$	52	14	16.8	24.2
$C_T = C_{gs} + (1+15)C_{gd} + C_{ds}$	55.5	17	18.8	26.2
$F_T = g_m / C_T \quad \times 10^6$ r/s	28.8	135	319	228

(c) Yes, C_{gd} does affect HF performance.

8.21

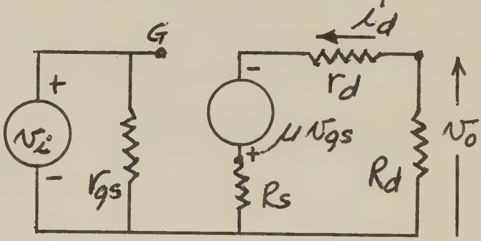
6AK5 Pentode: $F_T = 705 \times 10^6$

Best FET is #3: $F_T = 319 \times 10^6$

FET #3 will not improve performance.

8.22

(a)



$$v_o = -R_d \, i_d$$

$$i_d = \frac{\mu(v_i - R_s i_d)}{r_d + R_d + R_s}$$

$$\mu = g_m r_d = 40$$

$$A_{vr} = \frac{v_o}{v_i} = \frac{-\mu R_d}{r_d + R_d + (\mu+1) R_s}$$

(b) $$A_{vr} = \frac{-40 \times 50}{20 + 50 + 41} = -18$$

If we bypass R_s with a large capacitor or if we remove R_s the gain is increased markedly.

$$A_{vr} = \frac{-40 \times 50}{20 + 50} = -28.6$$

8.23

$$R_K = \frac{E_K}{I_b} = \frac{2}{1.2} = 1.67 \text{ k}\Omega$$

$$\omega_1 = 2\pi f_1 = 2\pi(15) = 94.5 \text{ r/s}$$

8.23 (Concl.)

In this instance $r_p = 7R_L$ so we can use the equations derived in section 8.13 for the pentode.

$$\omega_{KK} = (1 + g_m R_K)\omega_K, \quad g_m = \frac{100}{70\times10^3} = 1430\ \mu\mho$$

$$\omega_K = \frac{\omega_{KK}}{(1+1430\times10^{-6}\times1.67\times10^3)} = \frac{\omega_1}{3.38} = \frac{94.5}{3.38}$$

$$\omega_K = 28\ r/s, \quad C_K = \frac{1}{1.67\times10^3\times28} = 21.4\ \mu f$$

Since we have made $\omega_{KK} = \omega_1$, we must make $\omega_c << \omega_1$, say

$$\omega_c = \frac{\omega_1}{5} = \frac{94.5}{5} = 18.9\ r/s$$

$$C_c = \frac{1}{(R_L \| r_p + R_g)\omega_c} = \frac{1}{209\times10^3\times18.9}$$

$$C_c = 0.253\ \mu f$$

Another possibility is to make

$$\omega_c = \omega_1 \text{ and } \omega_{KK} = \frac{\omega_1}{5}, \text{ i.e.,}$$

$$C_c = \frac{0.253}{5} = 0.051\ \mu f$$

$$C_K = 5\times21.4 = 107\ \mu f$$

$$\omega_K = \frac{28}{5} = 5.6\ r/s$$

Bode plot has zero at 5.6 r/s and poles at 94.5 and 18.9 r/s.

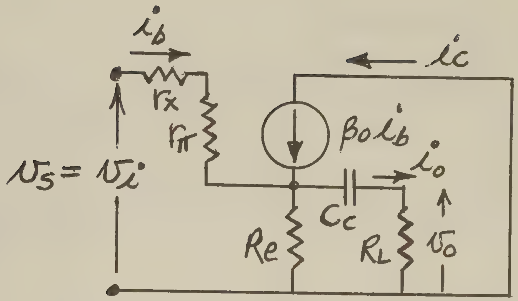
8.24

Assuming

$R_s << R_b \| R_{in}$

we get $v_s = v_i$

Let $i = i_b + i_c$



$$I_o(s) = \frac{R_e\, I(s)}{R_e + R_L + \frac{1}{sC_c}} = \frac{s R_e\, I(s)}{(R_e + R_L)(s + \omega_c)}$$

$$A_i(s) = \frac{I_o(s)}{I_b(s)} = \frac{s(\beta_o + 1) R_e}{(R_e + R_L)(s + \omega_c)}$$

where $\omega_c = \dfrac{1}{(R_e + R_L)\, C_c}$

$$V_o(s) = R_L\, I_o(s) = R_L\, A_i(s)\, I_b(s)$$

$$I_b(s) = \frac{V_i(s)}{r_x + r_\pi + (\beta_o + 1) Z_{eL}(s)} = \frac{V_i(s)}{r_x + r_\pi + \frac{(\beta_o + 1) R_{eL} (s + \omega_o)}{s + \omega_c}}$$

where

$$Z_{eL}(s) = \frac{R_e\left(R_L + \frac{1}{sC_c}\right)}{R_e + R_L + \frac{1}{sC_c}} = \frac{R_{eL}(s + \omega_o)}{(s + \omega_c)}$$

$$\omega_o = \frac{1}{R_L C_c} \quad \text{and} \quad R_{eL} = \frac{R_e R_L}{R_e + R_L}$$

$$V_o(s) = \frac{s(\beta_o + 1) R_{eL}}{(s + \omega_c)} \cdot \frac{V_i(s)}{r_x + r_\pi + (\beta_o + 1) R_{eL} \frac{(s + \omega_o)}{(s + \omega_c)}}$$

8.24 (Concl.)

$$A_v(s) = \frac{(\beta_o+1)R_{eL}}{[r_x + r_\pi + (\beta_o+1)R_{eL}]}\left[\frac{s}{s+\omega_1}\right]$$

where $$\omega_1 = \frac{(r_x+r_\pi)\omega_c + R_{eL}(\beta_o+1)\omega_o}{r_x+r_\pi+(\beta_o+1)R_{eL}}$$

Substituting numerical values, we get

$$\omega_1 = \frac{1350\,\omega_c + 2550\,\omega_o}{1350+2550} = 0.346\,\omega_c + 0.655\,\omega$$

$$\omega_c = \frac{1}{1050 C_c} \quad \text{and} \quad \omega_o = \frac{1}{50 C_c}$$

$$\omega_1 = \frac{0.346}{1050 C_c} + \frac{0.655}{50 C_c} = \frac{1.343\times 10^{-3}}{C_c}$$

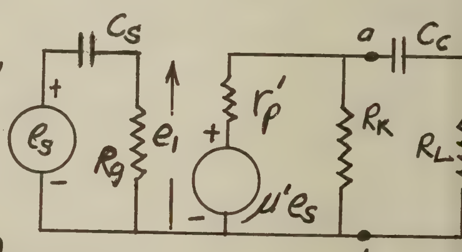
$$C_c = \frac{1.343\times10^{-3}}{2\pi(20)} = 10.7\ \mu f$$

$$A_{ir} = \frac{(50+1)1000}{1000+50} = 48.5$$

$$A_{vr} = \frac{51\times 50}{1350+2550} = 0.655$$

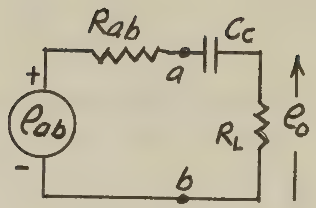
8.25

Using the Thévenin equivalent of Fig 6.27(b), we can derive the expression for $A_{vL}(s) = E_o(s)/E_s(s)$.



Neglecting for the moment C_s and assuming $e_t = e_s$, we have

3.25 (Concl.)



$$E_o(s) = \frac{R_L E_{ab}(s)}{r_p' + R_{ab} + \frac{1}{sC_c}}$$

where
$$e_{ab} = \frac{R_K \mu' e_s}{r_p' + R_K}$$

$$e_{ab} = \frac{\mu R_K e_s}{r_p + (\mu+1)R_K} \quad \& \quad R_{ab} = \frac{r_p R_K}{r_p + (\mu+1)R_K}$$

$$E_o(s) = \frac{R_L s\, E_{ab}(s)}{(R_{ab}+R_L)(s+\omega_c)} \quad \& \quad \omega_c = \frac{1}{(R_{ab}+R_L)C_c}$$

$$E_o(s) = \frac{\mu' R_K R_L E_s(s)}{r_p'(R_K+R_L)+R_K R_L}\left[\frac{s}{s+\omega_c}\right] = A_{vr}\left[\frac{s}{s+\omega_c}\right]E_s(s)$$

The input circuit introduces another pole and zero, i.e.,

$$A_{vL}(s) = \frac{E_o(s)}{E_s(s)} = A_{vr}\left[\frac{s}{s+\omega_c}\cdot\frac{s}{s+\omega_s}\right]$$

(b) $\mu' = \frac{19}{19+1} = 0.95$, $r_p' = \frac{8000}{19+1} = 400\ \Omega$

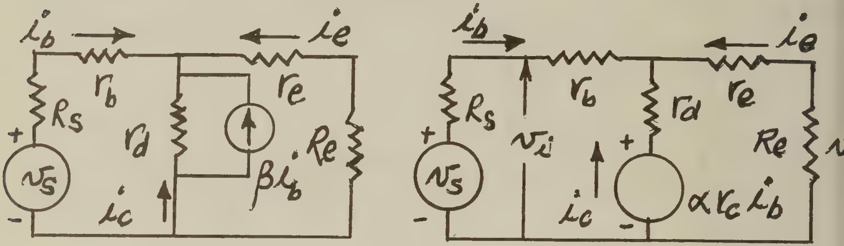
$$\omega_c = \frac{1}{[400 \| 20{,}000 + 100]\,10^{-6}} = 2030\ r/s$$

$$\omega_s = \frac{1}{R_g C_s} = \frac{1}{1\times10^6 \times 0.02\times10^{-6}} = 50\ r/s$$

$A_{vr} = 0.19$, (c) By using a tube with larger g_m or by decreasing R_K.

8.26 Correction: In Fig P8.26 replace $\alpha V_c i_b$ with $\alpha r_c i_b$.

Using the incremental of Fig 5.23(b) on page 222, we obtain



The loop equations are

$$v_i = (r_b + r_d) i_b + \alpha r_c i_b + r_d i_e = (r_b + r_c) i_b + r_d i_e$$

$$0 = (r_d + \alpha r_c) i_b + (r_e + r_d + R_e) i_e = r_c i_b + (r_e + r_d + R_e) i_e$$

$$A_i = \frac{-r_c}{r_e + r_d + R_e} \doteq -(\beta + 1) \quad \text{For } r_d \gg r_e + R_e$$

Substitute for i_e in expression for v_i

$$R_i = r_b + \frac{r_c (r_e + R_e)}{r_e + (1-\alpha) r_c + R_e} = r_b + \frac{r_c (\beta+1)(r_e + R_e)}{r_c + (\beta+1)(r_e + R_e)}$$

From the outside loop equation, we have

$$v_i = r_b i_b - (r_e + R_e) i_e = [r_b - (r_e + R_e) A_i] i_b$$

$$A_v = \frac{-R_e A_i}{r_b - (r_e + R_e) A_i} \doteq \frac{(\beta+1) R_e}{r_b + (r_e + R_e)(\beta + 1)}$$

8.27

$$A_{vH}(s) = \frac{R_e}{R_s + r_x + R_e}\left[\frac{s + (\beta_o + 1)\omega_\beta}{s + \omega_{\beta e}}\right]$$

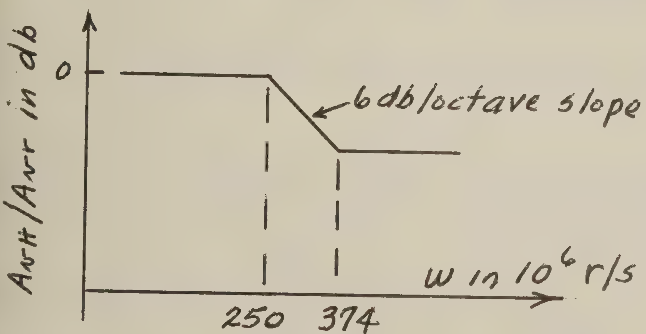
Letting $s \to 0$, we get the expression for A_{vr}

$$A_{vr} = \frac{(\beta_o + 1) R_e \omega_\beta}{(R_s + r_x + R_e)\omega_{\beta e}}$$

$$A_{vH}(s) = A_{vr}\left[\frac{\omega_{\beta e}[s + (\beta_o + 1)\omega_\beta]}{(\beta_o + 1)\omega_\beta(s + \omega_{\beta e})}\right]$$

$$A_{vH}(s) = 0.965\left[\frac{250 \times 10^6 [s + 374 \times 10^6]}{374 \times 10^6 (s + 250 \times 10^6)}\right]$$

$$= 0.645\left[\frac{s + 374 \times 10^6}{s + 250 \times 10^6}\right]$$



CHAPTER 9

9.1 $A_{vL}(j\omega) = \dfrac{A_{vr}}{1 + j\, f_1/f}$

At $f = f_1$, $\left[1 + \left(\dfrac{f_1}{f_1}\right)^2\right]^{1/2} = \sqrt{2}$ (for single stage)

At $f = f_{1(n)}$,

$$\left[1 + \left(\frac{f_1}{f_{1(n)}}\right)^2\right]^{\frac{n}{2}} = \sqrt{2} \quad \text{(for } n \text{ stages)}$$

$$\left[1 + \left(\frac{f_1}{f_{1(n)}}\right)^2\right]^{n} = 2$$

$$\frac{f_{1(n)}^2 + f_1^2}{f_{1(n)}^2} = 2^{1/n} \text{ and } f_{1(n)} = \frac{f_1}{\sqrt{2^{1/n} - 1}}$$

In a similiar manner we can derive the expression for $f_{2(n)}$

$$f_{2(n)} = f_2 \sqrt{2^{1/n} - 1}$$

9.2 The original quiescent values are:

$V_{CE1} = V_{CE2} = -5\,V$	$V_{CE3} = -5\,V$
$I_{C1} = I_{C2} = -1\,ma$	$I_{C3} = -3\,ma$
$I_{B1} = I_{B2} = -33\,\mu a$	$I_{B3} = -100\,\mu a$

9.2 (Cont.)

In the calculations that follow let us drop the minus signs associated with the currents and voltages.

$$V_{CC} = V_{CE3} + R_{C3} I_{C3} + R_{E3} I_{E3}$$

$$R_{C3} = \frac{12-5-3.1}{3} = 1.30\,k\Omega \quad \left(\begin{array}{l}\text{USE RETMA}\\ 1300\,\Omega,\ 5\%\end{array}\right)$$

Keeping $R_{b3} = 10\,k\Omega$, we get for S_I

$$S_I = \frac{31(1.10)}{1+31(0.10)} = 8.3$$

$$V_{BB3} = (R_{b3}+R_{E3}) I_{B3} + R_{E3} I_{C3} + V_{BE3}$$

$$= (10+1)(0.10) + (1)(3) + 0.20 = 4.3\,V$$

$$R_4 = \frac{10 \times 12}{4.3} = 27.9\,k\Omega \text{ (USE RETMA } 27\,k\Omega)$$

$$R_3 = \frac{10 \times 27}{27-10} = 15.9\,k\Omega \text{ (USE RETMA } 16\,k\Omega)$$

These values are the same as those for $V_{CC} = -20V$.

(c) Stages #1 & #2

$$R_{C1} = R_{C2} = \frac{12-5-1.033}{1} = 6\,k\Omega \quad \left(\begin{array}{l}\text{USE}\\ \text{RETMA } 6200\,\Omega\end{array}\right)$$

$$V_{BB1} = (10+1)(0.033) + (1)(1) + 0.20 = 1.56\,V$$

$$R_2 = \frac{10 \times 12}{1.56} = 77\,k\Omega \text{ (USE RETMA } 75\,k\Omega)$$

$$R_1 = \frac{10 \times 77}{77-10} = 11.50\,k\Omega \text{ (USE RETMA } 12\,k\Omega)$$

9.2 (Cont.) These values the same as those for $V_{cc} = -20$ V.

$\omega_{d1} = \omega_1 = \omega_{es} + \omega_{ss} = 96$ r/s (see Text pp 510)

$$\omega_{ss} = \frac{1}{R_{ss} C_s} \quad \text{and} \quad \omega_{es} \doteq \frac{1+\beta_o}{R_{ss} C_e}$$

Since $R_{ss} = r_x + r_\pi + R_s$ is not affected by the reduction in V_{cc}, the following capacitors remain the same:

$C_{e1} = C_{e2} = C_{e3} = 200\ \mu f$

$C_s = 10\ \mu f$

$$C_{c1} = C_{c2} = \frac{1}{\omega_c [R_c + R_b \| (r_x + r_\pi)]}$$

Let $f_c = 5$ Hz and $\omega_c = 31.4$ r/s

$$C_{c1} = C_{c2} = \frac{1}{31.4[6200 + 10{,}000 \| 1500]} = 4.25\ \mu f$$

Use 5 μf capacitors.

$$C_{c3} = \frac{1}{31.4[1300 + 1000]} = 13.85\ \mu f$$

Use 15 μf, 20 v d-c capacitor.

$$A_{ir(3)} = \frac{I_o}{I_s} = k_1 k_2 k_3 k_4 \beta_{o1} \beta_{o2} \beta_{o3}$$

$k_1 = 0.87$ (same as 20 V), $k_2 = k_3 = 0.72$

$k_4 = 0.565$

9.2 (Concl)

$$A_{ir(3)} = 0.255 \times 27{,}000 = 6880$$

$$A_{vr(3)} = \frac{-R_{load}\,A_{ir(3)}}{[R_{b1} \| (r_{x1} + r_{\pi 1})]} = \frac{-1 \times 6880}{10 \| 1.50} = -5300$$

$$G = -A_{ir(3)}\,A_{vr(3)} = 6880 \times 5300 = 36.4 \times 10^6$$

$$G_{db} = 10 \text{ Log } 3.64 \times 10^7 = 75.6 \text{ db}$$

Required gain is 58 db so the design is alright. The reduction in V_{cc} from -20 V to -12 V is desirable, especially if the source of polarizing power is a battery.

9.3 (a)

$$R_b = \frac{10 \times 50}{10 + 50} = 8.33 \text{ k}\Omega$$

$$V_{BB} = \frac{20 \times 10}{10 + 50} = 3.33 \text{ V}$$

$$I_B = \frac{3.33 - 0.3}{8.33 + (49+1)(1)} = 0.052 \text{ ma}$$

$$I_C = 49(0.052) = 2.55 \text{ ma}, \quad I_E = 2.60 \text{ ma}$$

$$V_{CE} = 20 - 2.55(2) - 50(0.052) = 12.3 \text{ V}$$

$$S_I = \frac{50(8.33+1)}{50 + 8.33} = 8$$

9.3 (Cont.)

(b)

$$g_m = \frac{2.55}{26} = 0.098 \ \mho$$

$$r_\pi = \frac{49}{0.098} = 500\ \Omega, \quad r_x = 530 - 500 = 30\ \Omega$$

$$C_\pi + C_\mu = \frac{0.098}{2\pi(400\times10^6)} = 39\ pf$$

$$C_\pi = 39 - 2 = 37\ pf$$

$$R_{b1} = R_{b2} = R_{b3} = \frac{R_1 R_2}{R_1 + R_2} = \frac{10\times50}{10+50} = 8.33\ k\Omega$$

$$r_o \doteq \frac{1}{h_{oe}} = \frac{1}{50\times10^{-6}} = 20\ k\Omega$$

$$R_{b2} \| R_{c2} = R_{b3} \| R_{c3} = 8.33 \| 2 = 1.61\ k\Omega$$

$$R_{obc} = r_o \| R_{b2} \| R_{c2} = 20 \| 1.61 = 1.49\ k\Omega$$

$$A_{ir(3)} = \frac{i_o}{i_s} = k_1 k_2 k_3 k_4 \beta_o^3$$

$$k_1 = \frac{R_{b1}}{r_x + r_\pi + R_{b1}} = \frac{8.33}{0.530 + 8.33} = 0.94$$

$$k_2 = \frac{R_{obc}}{r_x + r_\pi + R_{obc}} = \frac{1.49}{0.530 + 1.49} = 0.74$$

$$k_3 = k_2 = 0.74, \quad k_4 = \frac{R_{oc3}}{R_{oc3} + R_{load}} = \frac{2\|20}{2\|20 + .50}$$

$$k_4 = \frac{1.82}{1.82 + 0.50} = 0.785$$

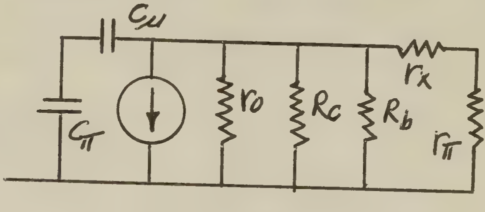
$$A_{ir(3)} = (0.94)(0.74)^2(0.785)(49)^3 = 47.5\times10^3$$

9.3 (Cont.)

$$A_{vr(3)} = \frac{v_o}{v_s} = \frac{R_{load}\, i_o}{R_{in}\, i_s}$$

$$A_{vr(3)} = \frac{R_{load}\, A_{ir(3)}}{R_{bi} \| (r_x + r_\pi)} = \frac{47.5\times10^3 \times 500}{498} = 47.5\times10^3$$

(c)



$$C_{\pi t} = C_\pi + (1 + g_m R) C_\mu$$

$$R = 1490 \| 530$$
$$R = 391\ \Omega$$

$$R = r_o \| R_c \| R_b \| (r_x + r_\pi)$$
$$= R_{obc} \| (r_x + r_\pi)$$

$$C_{\pi t} = 37 + (1 + 0.098\times391)(2)$$
$$= 37 + 78.8 = 116\ pf$$

$$\omega_2 = \omega_\pi = \frac{1}{R_{eq}\, C_{\pi t}}$$

$$R_{eq} = r_\pi \| (r_x + R_b \| R_s) = 500 \| (30 + 470) = 250\ \Omega$$

$$\omega_2 = \omega_\pi = \frac{1}{250\times116\times10^{-12}} = 34.4\times10^6\ r/s$$

$$f_2 = f_\pi = 5.48\ MHz$$

$$f_{2(3)} = 0.51\times5.48 = 2.79\ MHz$$

$$\omega_1 = \omega_d = \omega_{ss} + \omega_{es}$$

$$\omega_{ss} = \frac{1}{R_{ss} C_c} = \frac{1}{1030\times5\times10^{-6}} = 194\ r/s$$

$$\omega_{es} \doteq \frac{1+\beta_o}{R_{ss} C_e} = \frac{1+49}{1030\times100\times10^{-6}} = 485\ r/s$$

$$\omega_1 = \omega_d = 194 + 485 = 679\ r/s$$

9.3 (Concl.) $f_1 = 108\ Hz$

$$f_{1(3)} = 1.96 \times 108 = 212\ Hz$$

(d)

$$k_1 = 0.94, \quad R_{oDC} = 20 \| 8.33 \| 1 = 20 \| 0.893 = 0.855$$

$$k_2 = k_3 = \frac{855}{530 + 855} = 0.617$$

$$k_4 = \frac{20\|1}{20\|1 + 0.50} = \frac{0.955}{1.45} = 0.658$$

$$A_{ir(3)} = (0.94)(0.617)^2(0.658)(49)^3 = 0.236 \times 117{,}600$$
$$= 27.1 \times 10^3$$

$$A_{vr(3)} = 27.1 \times 10^3 \left(\frac{500}{498}\right) = 27.1 \times 10^3$$

$$\omega_2 = \omega_\pi = \frac{1}{250\ C_{\pi t}}; \quad R = R_{oDC} \| (r_x + r_\pi)$$
$$= 855 \| 530 = 328$$

$$\omega_2 = \omega_\pi = \frac{10^{12}}{250 \times 106}; \quad C_{\pi t} = 37 + (1 + 0.098 \times 328)(2)$$
$$= 37 + 66 = 106\ pf$$

$$\omega_2 = 37.7 \times 10^6\ r/s; \quad f_2 = 6.0\ MHz$$

$$f_{2(3)} = 0.51 \times 6.0 = 3.06\ MHz$$

(e)

Yes, because an $f_2 = 1.960 \times 4 = 7.84\ MHz$ is required and this is only 31% higher than the f_2 calculated in (d). Since we have an abundance of gain this increase in f_2 is easily obtained.

9.4

$$A_{vr(n)} = 1000 \doteq \left(\frac{h_{fe}}{2}\right)^n = \left(\frac{100}{2}\right)^n = (50)^n$$

$n = 2$ Looks good: $\sqrt{1000} = 31.6 = k(100)$

$$k = 0.316 \text{ and } k \doteq \frac{R_C}{R_C + r_\pi + r_x}$$

2 Stage Design

$$\omega_2 = 1.55\,\omega_{2(2)} = 1.55(2\pi)(4\times10^6) = 39\times10^6 \text{ r/s}$$

$$\omega_2 = \omega_\pi = \frac{1}{R_{eq}C_{\pi t}}; \quad R_{eq} = [(R_C \| R_b) + r_x] \| r_\pi$$
$$\doteq R_C \| r_\pi \quad \left(\begin{matrix}\text{neglect } r_x\\ \text{and } R_b\end{matrix}\right)$$

$$g_m = 0.0385(1) = 0.0385\,℧$$

$$r_\pi = \frac{\beta_0}{g_m} = \frac{100}{0.0385} = 2600\,\Omega; \quad r_x = 2700 - 2600 = 100$$

$$C_\pi + C_\mu = \frac{0.0385}{2\pi\times300\times10^6} = 20.4\text{ pf} \doteq 21\text{ pf}$$

$$C_\pi = 21 - 3 = 18\text{ pf}$$

$$R_C = \frac{k(r_\pi + r_x)}{1-k} = \frac{0.316\times2700}{1-0.316} = 1250\,\Omega$$

$$R_{eq} = 1250 \| 2700 = 855\,\Omega$$

$$C_{\pi t} = 18 + (1 + 0.0385\times855)(3) = 18 + (1+33)(3)$$
$$= 18 + 102 = 120\text{ pf}$$

$$\omega_2 = \omega_\pi = \frac{10^{12}}{855\times120} = 9.75\times10^6 \left(\begin{matrix}\text{should be}\\ 39\times10^6\end{matrix}\right)$$

Try $n = 3$ stages.

9.4 (Cont.) 3 Stage Design

$A_i = k\beta_o = 100k = (1000)^{1/3} = 10 \; ; \; k = 0.10$

$R_C = \dfrac{0.10 \times 2700}{1-0.10} = 300\,\Omega \; ; \; R_{eq} = 300 \| 2700 = 270\,\Omega$

$C_{\pi t} = 18 + (1 + 0.0385 \times 270)(3) = 18 + (1 + 10.4)(3)$
$= 18 + 34.2 = 52.2\,pf$

$\omega_2 = \omega_\pi = \dfrac{10^{12}}{270 \times 52.2} = 71 \times 10^6\ r/s$

Required $\omega_2 = 1.96 \times 2\pi \times 4 \times 10^6 = 1.96 \times 25.10 \times 10^6$
$= 49.2 \times 10^6\ r/s$

If desired the gain A_i can be increased and ω_2 decreased. The essential point is that the high frequency requirements can be met with 3 stages.

Low Frequency Design

$f_1 = 0.51\, f_{r(3)} = 0.51 \times 30 = 15.3\ Hz$

$\omega_1 = 2\pi f_1 = 2\pi \times 15.3 = 96.2\ r/s$

$\omega_1 = \omega_d = \omega_{ss} + \omega_{es} = 96.2\ r/s$

Assume $C_s = 20\,\mu f$; $R_s = 1000\,\Omega$; $\omega_{ss} = \dfrac{10^6}{(2700+1000)(20)}$

$\omega_{ss} = 13.2\ r/s \; ; \; \omega_{es} = 96.2 - 13.2 = 83\ r/s$

$C_e = \dfrac{1+100}{83 \times 3800} = 320\,\mu f$

9.4 (Concl.)

Let $\omega_c = \dfrac{\omega_1}{3} = \dfrac{96.2}{3} = \dfrac{1}{(R_c + h_{ie})C_c}$

$$C_c = \frac{1}{(300+2700)(32)} = 10.4\,\mu f$$

BIAS CIRCUIT DESIGN

$V_{cc} = R_c I_c + V_{CE} + R_e I_E = 0.30(1) + 10 + 1.7 = 12 \text{ V}$

$R_e \doteq \dfrac{1.7}{1.0} = 1.70\ k\Omega$ (Use RETMA 1800 Ω)

$V_{BB} = R_b I_B + V_{BE} + 1.80(1.00)$; $I_B = \dfrac{1}{100} = 0.01\ ma$

$V_{BB} = 15(0.01) + 0.20 + 1.80$
$= 2.15$ V

$R_b > 5 \times 2700 = 13{,}500$
Use $R_b = 15{,}000\ \Omega$

$$R_2 = \frac{R_b V_{cc}}{V_{BB}} = \frac{15 \times 12}{2.15} = 84\ k\Omega$$

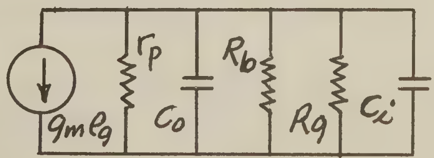
Use RETMA 82 kΩ for R_2.

$$R_1 = \frac{R_b R_2}{R_2 - R_b} = \frac{15 \times 82}{82 - 15} = 18.3\ k\Omega$$

Use RETMA 18 kΩ for R_1.

9.5 (a)

Refer to Fig 8.6 and Fig 9.2(b).



$f_2 = 1.96 \times 4 = 7.84$ MHz

$f_1 = 0.51 \times 30 = 15.3$ Hz

9.5 (Cont.) $\quad C_t = C_o + C_i'$

$$C_o = 2.8 + 0.02 + 4 = 6.82$$

$$C_i = 4.0 + 4.0 + (1 + g_m R_b)(0.02)$$

$$C_t = 6.82 + 8.0 + (1 + g_m R_b)(0.02)$$

To avoid a quadratic equation let us assume a value for $(1 + g_m R_b) = 10$ and then correct the assumption if it is far off.

$$C_t = 6.82 + 8.0 + 0.20 = 15 \ pf$$

$$\omega_2 = \frac{1}{R_{bgp} C_t} \quad \text{where } R_{bgp} = r_p \| R_b \| R_g$$

$$R_{bgp} = \frac{1}{\omega_2 C_t} = \frac{1}{2\pi (7.84 \times 10^6)(15 \times 10^{-12})}$$

$$R_{bgp} = 1350 \, \Omega \quad \text{and} \quad R_b \doteq 1350 \, \Omega$$

$$A_{vr} = -g_m R_{bgp} = -5100 \times 10^{-6} \times 1350 = -6.9$$

$$E_{bb} = R_b I_b + E_b + E_k = 1.35(7.7) + 180 + 2$$

$$= 10.4 + 180 + 2 = 192 \, V$$

$$R_d = \frac{192 - 120 - 2}{2.4} = 29.2 \, k\Omega$$

$$R_K = \frac{E_K}{I_b + I_d} = \frac{2}{7.7 + 2.4} \doteq 200 \, \Omega$$

9.5 (Cont.) (b) $A_{vr} = -6.9$ (see part (a))

$A_{vr(3)} \doteq (-6.9)^3 = -328$

(c)

Capacitance Calculations

From Eq (8.105) pp 476, we get $A_{vL}(s)$.

$$A_{vL}(s) = A_{vr}\left[\frac{s^2(s+\omega_K)}{(s+\omega_s)(s+\omega_c)(s+\omega_{KK})}\right]$$

$\omega_1 = 2\pi f_1 = 2\pi(15.3) = 96.2$ r/s

Let $\omega_1 = \omega_{KK} = 96.2$ and then make $\omega_s = \omega_s = \omega_1/3 = 32$ r/s.

$\omega_{KK} = (1+g_m R_K)\omega_K = (1+5100\times10^{-6}\times200)\omega_K$

$$\omega_K = \frac{96.2}{2.02} = 48 \text{ r/s}$$

$$C_K = \frac{1}{R_K \omega_K} = \frac{1}{200\times 48} = 104\ \mu f$$

$$C_c = \frac{1}{(R_b+R_g)\omega_c} = \frac{1}{1.001\times10^6\times 32} = 0.0315\,\mu f$$

$$C_s = \frac{1}{(R_s+R_g)\omega_s} = \frac{1}{1.001\times10^6\times32} = 0.0315\,\mu f$$

(d) $A_{vr} = -6.9$, Req $A_{vr} = (1000)^{1/3} = 10$

$F_T(6AK5) = 705\times10^6$

$$F_T(\text{Required}) = \frac{10\times705\times10^6}{6.9} = 1022\times10^6$$

9.5 (Concl.) From Problem 8.4.

$F_T(6DK6) = 1140 \times 10^6$
$F_T(6JD6) = 1220 \times 10^6$

Either one of these pentodes will yield an $A_{vr(3)} > 1000$.

9.6 Because of the low output impedance we will use an emitter-follower output stage.

$P_o = 1\text{ mw}$ to a $50\,\Omega$ Cable

$$I_o = \sqrt{\frac{1 \times 10^{-3}}{50}} \doteq 4.5 \text{ ma (rms)}$$

$$V_o = R_o I_o = 50 \times 4.5 = 225 \text{ mv (rms)}$$

$$A_{vr} = \frac{V_o}{V_S} = \frac{225}{10} = 22.5 \text{ (gain required)}$$

$\therefore$ At least 2 stages are required. We will use an emitter follower driven by a CE stage.

To prevent bottom clipping make $I_E = 10$ ma.

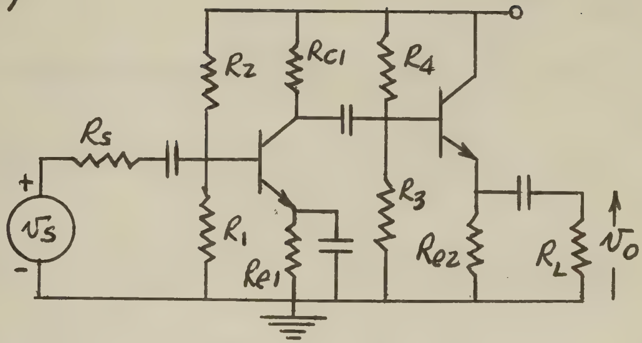
$$I_B \doteq \frac{I_E}{1+h_{fe}} = \frac{10}{1+100} \doteq 0.10 \text{ ma}$$

$$I_b \doteq \frac{I_o}{1+h_{fe}} = \frac{4.5}{1+100} \doteq 0.045 \text{ ma}$$

$$R_{out} = 50 \| R_e \doteq 50 = \frac{R_{s2} + (r_x + r_\pi)}{h_{fe}+1}$$

$R_{s2} = R_{b2} \| R_{c1}$ (See circuit on next page.)

9.6 (Cont.)



Let us now design the bias circuit for the first stage. After which we will return to the output stage.

$$I_{cm} \doteq 2\, I_{b2m} = 2\sqrt{2}\,(0.045) = 0.137 \text{ ma}$$

A quiescent value of $I_{C1} = 1$ ma sufficient.

$$I_{B1} \doteq \frac{I_{C1}}{h_{fe1}} = \frac{1}{50} = 0.02 \text{ ma}$$

Assume $V_{CE1} = 5$ V & $S_I = 8$

$$\frac{R_{e1}}{R_{b1}} = \frac{(h_{fe}+1) - S_I}{(h_{fe}+1)(S_I - 1)} = \frac{51-8}{51\times 7} = 0.12$$

$R_{b1} = 5000\ \Omega$ (Note this is only 2.5 h_{ie1}, but let us try it.)

$$R_{e1} = 5000 \times 0.12 = 600\ \Omega$$

$$V_{BB1} = I_{B1}\left[R_{b1} + (h_{fe1}+1)R_{e1}\right] + V_{BE1}$$

$$= 0.02\left[5 + 51(0.60)\right] + 0.30 = 1.01 \text{ V}$$

9.6 (Cont.)

$$R_2 = \frac{R_{b1} V_{CC}}{V_{BB1}} = \frac{5 \times 20}{1} = 100\ k\Omega$$

$$R_1 = \frac{R_2 R_{b1}}{R_2 - R_{b1}} = \frac{100 \times 5}{100-5} = 5.25\ k\Omega$$

$$R_{C1} = \frac{V_{CC} - V_{CE1} - R_{E1}(I_{C1} + I_{B1})}{I_{C1}}$$

$$= \frac{20 - 5 - 0.6(1.02)}{1} = 14.4\ k\Omega$$

Now we evaluate $R_{S2} = R_{b2} \| R_{C1}$ and R_{b2}.

$$R_{out} = 50 \| R_E \doteq 50 = \frac{R_{S2} + h_{ie2}}{h_{fe2}+1}$$

$$R_{S2} = 50(100+1) - 500 = 5050 - 500 = 4550\ \Omega$$

$$R_{S2} \doteq \frac{R_{C1} R_{b2}}{R_{C1} + R_{b2}} \quad \text{and} \quad R_{b2} = \frac{R_{S2} R_{C1}}{R_{C1} - R_{S2}}$$

$$R_{b2} = \frac{4.55 \times 14.4}{14.4 - 4.55} = 6.65\ k\Omega$$

$$V_{CC} = V_{CE2} + R_{E2} I_{E2} = 10 + R_{E2}(10.10)$$

$$R_{E2} = \frac{20-10}{10.10} \doteq 1000\ \Omega$$

The voltage gain $A_{vr} = \dfrac{v_o}{v_s}$ is calculated as follows:

9.6 (Concl.)

$$v_o = (h_{fe2}+1)(R_{e2} \| R_L) i_{b2} = 101 \times 0.0475\, i_{b2}$$

$$= 4.810\, i_{b2} \quad (i_{b2} \text{ is in ma})$$

$$i_{b2} = h_{fe1} i_{b1} \left[\frac{R_{c1} \| R_{b2}}{R_{c1} \| R_{b2} + h_{ie2} + (h_{fe2}+1)(R_{e2} \| R_L)} \right]$$

$$= 50 \left[\frac{4.55}{4.55 + 0.50 + 4.8} \right] i_{b1} = 50(0.465)\, i_{b1}$$

$$i_{b1} = \frac{v_s}{R_s + R_{b1} \| h_{ie1}} \left[\frac{R_{b1}}{R_{b1} + h_{ie1}} \right] = \frac{v_s}{3.43} \left[\frac{5}{5+2} \right]$$

$$i_{b1} = 0.282(0.715)\, v_s \quad \text{in ma} \; ; \; k_1 = 0.715$$

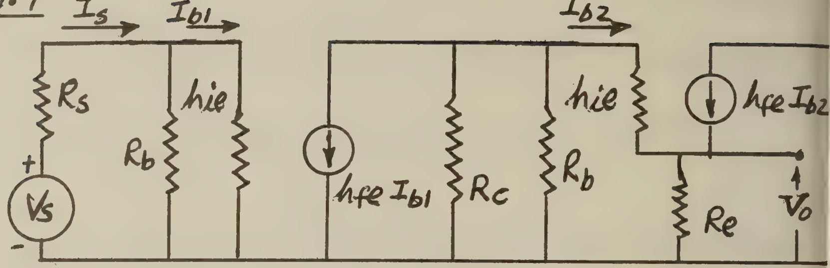
$$v_o = 4.81\, i_{b2} = 4.81 \times 50 \times 0.465 \times 0.282 \times 0.715\, v_s$$

$$A_{vr} = \frac{v_o}{v_s} = 22.5$$

The required value is also 22.5 so the design is marginal. Increasing R_{b1} to 10 kΩ, increases k_1 to 0.833, and the gain is

$$22.5 \left(\frac{0.833}{0.715} \right) = 26.2$$

9.7



$$I_o = (1+h_{fe}) I_{b2}$$

$$I_{b2} = -k_2 h_{fe} I_{b1} \; ; \quad k_2 = \frac{R_b \| R_c}{R_b \| R_c + h_{ie} + (1+h_{fe}) R_e}$$

$$I_{b1} = k_1 I_s \qquad k_2 = \frac{3.21}{3.21 + 1.5 + 5.1} = 0.327$$

$$k_1 = \frac{R_b}{R_b + h_{ie}} = \frac{9}{9+1.5} = 0.858$$

$$A_{i(2)} = -k_1 k_2 h_{fe} (1+h_{fe})$$

$$= -0.858 \times 0.327 \times 50 \times 51 = -715$$

$$A_{v(2)} = \frac{V_o}{V_s} = \frac{R_e A_{i(2)}}{R_s + R_b \| h_{ie}} = \frac{0.10(-715)}{1 + 9 \| 1.5} = -31.3$$

$$\omega_s = \frac{1}{(R_s + R_b \| h_{ie})} = \frac{1}{(1+1.285)10^3 \times 5 \times 10^{-6}} = 87.5 \text{ r/s}$$

$$\omega_e = \frac{1}{R_e C_e} = \frac{1}{1000 \times 200 \times 10^{-6}} = 5 \text{ r/s}$$

$$\omega_d = \omega_{es} + \omega_{ss}$$

9.7 (Concl.)

$$\omega_{es} \doteq \frac{(1+\beta_0)}{R_{ss} C_e} = \frac{51}{2500 \times 200 \times 10^{-6}} = 102 \text{ r/s}$$

$$\omega_{ss} = \frac{1}{R_{ss} C_s} = \frac{1}{2500 \times 5 \times 10^{-6}} = 80 \text{ r/s}$$

$$\omega_d = \omega_{es} + \omega_{ss} = 102 + 80 = 182 \text{ r/s}$$

$$\omega_m = \frac{\omega_e \omega_{ss}}{\omega_d} = \frac{5 \times 80}{182} = 2.2 \text{ r/s}$$

$$\omega_c = \frac{1}{\{R_c + R_b \| [h_{ie} + (1+\beta_0) R_{e2}]\} C_c}$$

$$= \frac{1}{\{[5 + 9 \| (1.5 + 5.1)] 10^3 \times 5 \times 10^{-6}} = 22.7 \text{ r/s}$$

$$R_{out} = \frac{R_s + r_\pi + r_x}{\beta_0 + 1} = \frac{1000 + 1500}{50 + 1} = 49\,\Omega$$

9.8 (a)

$$n_3 = \left[\frac{r_{oe}}{R_L}\right]^{1/2} = \left[\frac{1.25 \times 10^4}{8}\right]^{1/2} = 39.4$$

$$n_2 = \left[\frac{r_{oe}}{h_{ie}}\right]^{1/2} = \left[\frac{1.25 \times 10^4}{2000}\right]^{1/2} = 2.5$$

$$n_1 = \left[\frac{R_s}{h_{ie}}\right]^{1/2} = \left[\frac{1000}{2000}\right]^{1/2} = 0.707$$

$$r_{oe} = \frac{1}{h_{oe}} = \frac{1}{80 \times 10^{-6}} = 1.25 \times 10^4\,\Omega$$

9.8 (Concl.)

$$I_o = n_3 I_{22} = \frac{n_3 h_{fe} I_{12}}{2} = \frac{n_3 n_2 h_{fe} I_{21}}{2}$$

$$= \frac{n_3 n_2 n_1 h_{fe}^2 I_s}{4} = \frac{(3.94)(2.5)(0.707)(50)^2 I_s}{4}$$

$$= 43{,}500\, I_s\,; \quad A_i = 43{,}500$$

(c) $$G = \frac{I_o^2 R_L}{I_s^2 R_s} = \frac{A_i^2 R_L}{R_s} = \frac{(4.35 \times 10^4)^2\, 8}{1000}$$

$$= 15.2 \times 10^6$$

9.9 Using the method of symmetrical components described in Section 9.5, we can write

$$e_{s1} = e_{sc} + e_{sd} \quad \text{and} \quad e_{s2} = e_{sc} - e_{sd}$$

$$e_{sc} = \frac{e_{s1} + e_{s2}}{2} \quad \text{and} \quad e_{sd} = \frac{e_{s1} - e_{s2}}{2}$$

$$e_{o1c} = \frac{-\mu R_b e_{sc}}{r_p + R_b + 2(\mu+1)R_K} \doteq \frac{-\mu R_b e_{sc}}{2(\mu+1)R_K}$$

$$e_{o1d} = \frac{-\mu R_b e_{sd}}{r_p + R_b} \qquad \text{where } 2(\mu+1)R_K \gg (r_p + R_b)$$

$$e_{o1} = e_{o1c} + e_{o1d} = -\mu R_b \left[\frac{e_{s1} + e_{s2}}{4(\mu+1)R_K} + \frac{e_{s1} - e_{s2}}{2(r_p + R_b)} \right]$$

$$\doteq \frac{-\mu R_b}{2} \left[\frac{e_{s1} - e_{s2}}{r_p + R_b} \right]$$

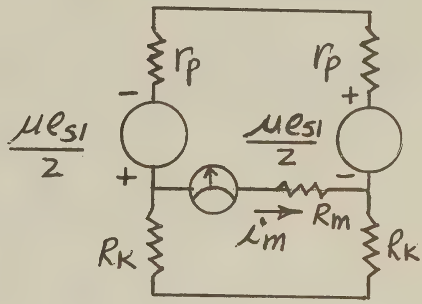
9.9 (Concl.)

$$e_{o2} \doteq \frac{-\mu R_b}{2}\left[\frac{e_{s2}-e_{s1}}{r_p+R_b}\right] = \frac{\mu R_b}{2}\left[\frac{e_{s1}-e_{s2}}{r_p+R_b}\right]$$

9.10 (a)

$$e_{sc} = \frac{e_{s1}+e_{s2}}{2} = \frac{e_{s1}}{2}$$

$$e_{sd} = \frac{e_{s1}-e_{s2}}{2} = \frac{e_{s1}}{2}$$



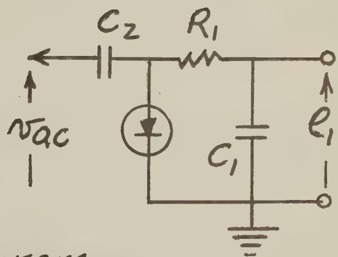
Difference Mode Circuit

$$i_m = \frac{\frac{\mu e_{s1}}{2} + \frac{\mu e_{s1}}{2}}{2r_p + R_M}$$

$$i_m \doteq \frac{\mu e_{s1}}{2r_p} = \frac{g_m e_{s1}}{2}$$

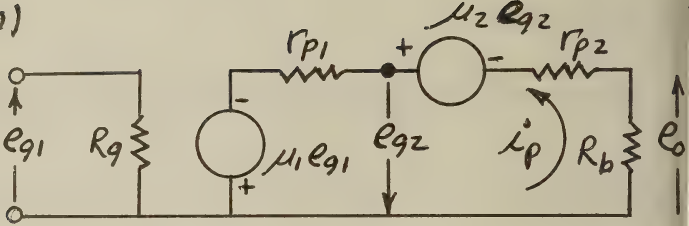
where $R_m << r_p$.

b)



An a-c probe that is often used with electronic voltmeters is shown in the adjacent circuit diagram. The voltage e_1 applied to the vacuum tube metering circuit of Fig P9.10 is negative. R_1 and C_1 serve as a filter.

9.11 (a)



Correction: In FIG P9.11 the output voltage e_o terminal should be on the plate end of R_b, i.e., the anode of T_2. Also the denominator of A_{vr} for identical triodes should be $R_b + (\mu+2) r_p$.

(b)

$$i_p = \frac{\mu_1 e_{g1} + \mu_2 e_{g2}}{r_{p1} + r_{p2} + R_b} \quad \text{and} \quad e_{g2} = \mu_1 e_{g1} - r_{p1} i_p$$

$$i_p = \frac{\mu_1(\mu_2+1) e_{g1}}{R_b + r_{p2} + (\mu_2+1) r_{p1}}$$

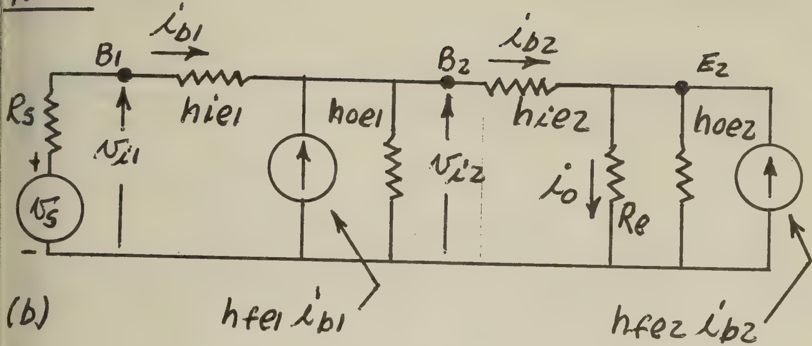
$$A_{vr} = \frac{e_o}{e_s} = \frac{-\mu_1(\mu_2+1) R_b}{R_b + r_{p2} + (\mu_2+1) r_{p1}}$$

For identical triodes

$$A_{vr} = \frac{-\mu(\mu+1) R_b}{R_b + (\mu+2) r_p} \doteq \frac{-\mu R_b}{r_p} = -g_m R_b$$

where $\mu \gg 1$ and $(\mu+2) r_p \gg R_b$

9.12 (a)



(b)

$$v_{i2} = h_{ie2}\, i_{b2} + R_{eo}(h_{fe2}+1)\, i_{b2}$$

$$R_{i2} = \frac{v_{i2}}{i_{b2}} = h_{ie2} + (h_{fe2}+1) R_{eo}$$

where $R_{eo} = R_e \,\|\, \left(\frac{1}{h_{oe2}}\right) = 1 \,\|\, 40 \doteq 1\ K\Omega$

$$R_{i2} = 1500 + 51(1000) = 52{,}500\ \Omega$$

$$v_{i1} = h_{ie1}\, i_{b1} + (h_{fe1}+1)\, i_{b1} R_{eq}$$

where $R_{eq} = \frac{1}{h_{oe1}} \,\|\, R_{i2} = 40 \,\|\, 52.5 = 22.7\ K\Omega$

$$R_{i1} = \frac{v_{i1}}{i_{b1}} = h_{ie1} + (h_{fe1}+1) R_{eq}$$

$$R_{i1} = 1500 + 51(22{,}700) = 1159\ K\Omega$$

If h_{oe} is assumed zero, then R_{i1} is 2681 $K\Omega$ which is the answer given in the text on page 873.

9.12 (Concl.)

$$i_o = \frac{(1+h_{fe2})\, i_{b2}}{1+h_{oe2} R_e} \quad \text{and} \quad i_{b2} = \frac{(1+h_{fe1})\, i_{b1}}{1+h_{oe1} R_{i2}}$$

$$A_{i(2)} = \frac{i_o}{i_{b1}} = \frac{(1+h_{fe1})(1+h_{fe2})}{(1+h_{oe1} R_{i2})(1+h_{oe2} R_e)}$$

$$A_{i(2)} = \frac{51 \times 51}{(1+25\times10^{-6}\times 52.5\times10^{3})(1+25\times10^{-6}\times10^{3})}$$

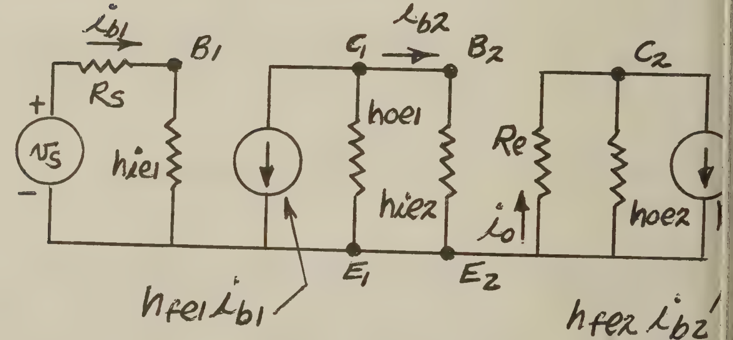
$$= \frac{2600}{1.025 \times 2.31} = 1100$$

$$A_{v(2)} = \frac{v_o}{v_s} = \frac{R_e\, i_o}{(R_s+R_{i1})\, i_{b1}} = \frac{R_e\, A_{i(2)}}{R_s+R_{i1}}$$

$$= \frac{(1)(1100)}{10+1159} = 0.94$$

9.13

(a)



$$i_o = \frac{h_{fe2}\, i_{b2}}{1+R_e h_{oe2}} = \frac{h_{fe1} h_{fe2}\, i_{b1}}{(1+h_{oe1} h_{ie2})(1+R_e h_{oe2})}$$

9.13 (concl.)

$$A_{i(2)} = \frac{i_o}{i_{b1}} = \frac{50 \times 50}{(1+25\times10^{-6}\times1.5\times10^3)(1+25\times10^{-6}\times10^3)}$$

$$= \frac{2500}{1.065} = 2350$$

$$A_{v(2)} = \frac{v_o}{v_s} = \frac{-R_e A_{i(2)}}{R_s + h_{ie1}} = \frac{-(1)(2350)}{10+1.5} = -205$$

$$R_i = h_{ie1} = 1500\,\Omega$$

9.14 $$F = \frac{P_{out}}{G P_n} = \frac{G P_g}{G P_n} = \frac{P_g}{P_n}$$

$$P_g = F P_n = F k T B_H = k T_g B_H$$

$$T_g = F T = 10 \times 290 = 2900\,^\circ K$$

Temperature of resistor is 2900°K; this is not a practical source of known noise power.

9.15 (a) $$I_{ns} = [2 e I_E B_H]^{1/2} = 5.66\times10^{-10}[I_E B_H]^{1/2}$$

$$= 5.66\times10^{-10}[5\times10^{-3}\times5\times10^{6}]^{1/2} = 8.97\times10^{-8}\,a$$

(b) $I_{ns} = 5.66\times10^{-10}[5\times10^{-3}\times5\times10^{6}]^{1/2} = 8.97\times10^{-8}\,a$

(c) $E_{nt} = [4 R_n k T B_H]^{1/2} = 5.25\times10^{-7}\sqrt{T}$

$E_{nt}(100^\circ) = 5.25\,\mu v$; $E_{nt}(300^\circ) = 9.1\,\mu v$; $E_{nt}(1000^\circ) = 16.6\,\mu v$

9.16

$$P_{out} = GkTB_H + P_{network}$$

$$4P_{out} = GkTB_H + P_{network} + GP_g = P_{out} + G$$

$$P_{out} = \frac{GP_g}{3}$$

$$F = \frac{P_{out}}{GkTB_H} = \frac{GP_g/3}{GkTB_H} = \frac{E_g^2}{3 \times 4R_g kTB_H}$$

$$E_g = \sqrt{2eI_bB_H}\, R_g$$

$$F = \frac{2eI_bB_HR_g^2}{(3)4R_gkTB_H} = \frac{eI_bR_g}{(3)2kT} = \frac{5800\, I_bR_g}{3T}$$

$$F = \frac{20\, I_bR_g}{3} \quad (\text{For } T = 290°K)$$

Eq (9.56) is: $\quad F = 20\, I_b R_g$

9.17

Signal-to-Noise Power Ratio $= \frac{S}{N} = \frac{P_{si}}{P_{ni}}$

P_{si} = Power of input signal

GP_{si} = Power of output signal $= P_{so}$

$$F = \frac{GP_{ni} + P_{network}}{GP_{ni}} = \frac{P_{no}}{GP_{ni}} \qquad \text{Eq (9.47)}$$

$$F = \frac{P_{no}}{\frac{P_{so}}{P_{si}}P_{ni}} = \frac{P_{no}P_{si}}{P_{so}P_{ni}} = \frac{P_{si}/P_{ni}}{P_{so}/P_{no}}$$

9.17 (Concl.)

$$F_{db} = 10 \log \frac{P_{si}/P_{ni}}{P_{so}/P_{no}} = 20 \log \frac{V_{si}/V_{ni}}{V_{so}/V_{no}}$$

9.18 (a)

$$R_{eq} \doteq \frac{2.5}{g_m} = \frac{2.5}{2000 \times 10^{-6}} = 1.25 \times 10^{3}\ \Omega$$

$$E_{eq}^2 = 4kTB_H R_{eq} = 4 \times 1.38 \times 10^{-23} \times 290\ B_H R_{eq}$$

$$E_{eq} = 1.265 \times 10^{-10} \sqrt{B_H R_{eq}}$$

$$= 1.265 \times 10^{-10} \sqrt{20{,}000 \times 1250} = 0.6325\ \mu v$$

$$E_{ns} = 1.265 \times 10^{-10} \sqrt{20{,}000 \times 2000} = 0.80\ \mu v$$

$$A_v = \frac{-\mu R_b}{r_p + R_b} = \frac{-100 \times 50}{50+50} = -50$$

$$A_v E_{ns} = 50 \times 0.80 = 40\ \mu v$$

$$A_v E_{eq} = 50 \times 0.6325 = 31.6\ \mu v$$

$$E_{nR_b} = 1.265 \times 10^{-10} \sqrt{20{,}000 \times 50{,}000} = 4.0\ \mu v$$

$$E_{Total} = \sqrt{(A_v E_{eq})^2 + (A_v E_{ns})^2 + E_{nR_b}^2}$$

$$= \sqrt{(31.6)^2 + (40)^2 + (4.0)^2} = 51\ \mu v$$

CHAPTER 10

<u>10.1</u> The admittance for the circuit in Fig 10.1(a) is

$$Y_T(s) = \frac{1}{R_p} + \frac{1}{sL} + sC = \frac{1}{R_p}\left[1 + R_p\left(sC + \frac{1}{sL}\right)\right]$$

$$Z_T(j\omega) = \frac{1}{Y_T(j\omega)} = \frac{R_p}{1 + jR_p\left(\omega C - \frac{1}{\omega L}\right)}$$

$$= \frac{R_p}{1 + jR_p\sqrt{\frac{C}{L}}\left[\omega\sqrt{LC} - \frac{1}{\omega\sqrt{LC}}\right]}$$

From Eq (10.10),

$$Z_T(j\omega) = \frac{R_p}{1 + jQ_0\left[\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right]}$$

<u>10.2</u> The impedance for the 2-branch circuit of Fig 10.2(a) is

$$Z_T(s) = \frac{1}{C}\left[\frac{s-p_0}{(s-p_1)(s-p_2)}\right]$$

For $Q_0 \geq 5$ and ω in the vicinity of ω_0, we can make the following approximatio[n]

$$Z_T(j\omega) = \frac{1}{C}\left[\frac{j\omega - p_0}{(j\omega - p_1)(j\omega - p_2)}\right] \doteq \frac{1}{C}\left[\frac{j\omega_0}{(j\omega - p_1)(j2\omega_0)}\right]$$

$$\doteq \frac{1}{2C}\left[\frac{1}{(j\omega + \alpha - j\beta)}\right] \doteq \frac{1}{2C}\left[\frac{1}{\alpha + j(\omega - \omega_0)}\right]$$

10.2 (Concl.) At ω_1 and ω_2 the real and the j-terms of the denominator are equal, so

$$\omega_2 - \omega_0 = \alpha \, , \quad \omega_0 - \omega_1 = \alpha$$

$$B = \omega_2 - \omega_1 = 2\alpha = \frac{\omega_0}{Q_0}$$

$$Q_0 = \frac{\omega_0}{2\alpha} = \frac{\omega_0}{\omega_2 - \omega_1}$$

The above expressions for the 2-branch circuit are seen to be the same as those for the 3-branch circuit.

10.3

$$E_0(s) = -g_m E_g(s)\, Z_T(s) = \frac{-g_m E_g(s)\, s}{(s-p_1)(s-p_2)}$$

For a step input voltage $e_g(t) = E_g u(t)$,

$$E_0(s) = \frac{-g_m E_g}{C}\left[\frac{A}{s-p_1} + \frac{B}{s-p_2}\right]$$

$$= \frac{-g_m E_g}{C}\left[\frac{1}{(s+\alpha)^2+\beta^2}\right]$$

where
$A = -j/2\beta$
$B = j/2\beta$

$$e_0(t) = \frac{-g_m E_g}{C\beta}\, \epsilon^{-\alpha t} \sin\beta t$$

$$\alpha = \frac{1}{2R_pC} \, , \quad \omega_0^2 = \frac{1}{LC} \, , \quad \beta^2 = \omega_0^2 - \alpha^2$$

10.4

$$f_2 = 502.5 + 0.10\,\%\,(502.5) = 502.5 + 0.5025$$

$$f_1 = 497.5 - 0.10\,\%\,(497.5) = 497.5 - 0.4975$$

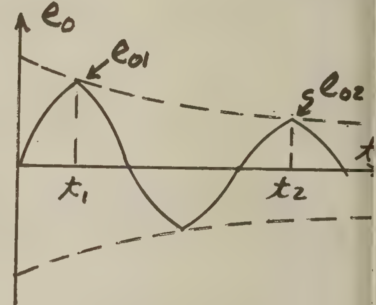
$$Q = \frac{f_o}{f_2 - f_1} = \frac{500}{502.5 - 497.5 + 0.5025 + 0.4975}$$

$$= \frac{500}{5+1} = 83.3 \quad (16.7\,\%\ \text{low})$$

$$Q = \frac{500}{5-1} = 125 \quad (25\,\%\ \text{high})$$

$$Q(\text{actual}) = \frac{500}{5} = 100$$

10.5 (a) & (b)



$$e_{o1} = \frac{-g_m E_g}{\beta C} \epsilon^{-\alpha t_1} \sin 90^\circ$$

$$e_{o2} = \frac{-g_m E_g}{\beta C} \epsilon^{-\alpha t_2} \sin 90^\circ$$

$$\frac{e_{o1}}{e_{o2}} = \epsilon^{\alpha(t_2 - t_1)} = \epsilon^{\alpha T} \quad \text{or} \quad \alpha T = \ln\left(\frac{e_{o1}}{e_{o2}}\right)$$

(c) From Section 10.2

$$Q = 2\pi f_o C R_p = \frac{2\pi C R_p}{T} = \frac{\pi}{\alpha T}$$

$$Q = \frac{\pi}{\ln(e_{o1}/e_{o2})}$$

10.5 (Concl.) (d)

$$\ln \frac{e_{o1}}{e_{o2}} = \frac{\pi}{50} = 0.0628$$

$$\frac{e_{o1}}{e_{o2}} = 1.065$$

(e)

$$\frac{e_{o1}}{e_{on}} = \frac{\epsilon^{-\alpha t_1}}{\epsilon^{-\alpha[t_1+(n-1)T]}} = \epsilon^{\alpha(n-1)T}$$

so $\quad Q = \dfrac{(n-1)\pi}{\ln(e_{o1}/e_{on})}$

(f) $\quad \ln \dfrac{e_{o1}}{e_{on}} = \dfrac{(11-1)\pi}{50} = 0.628$

$$\frac{e_{o1}}{e_{on}} = 1.87$$

A more accurate measurement of Q can be made by using a larger value of n.

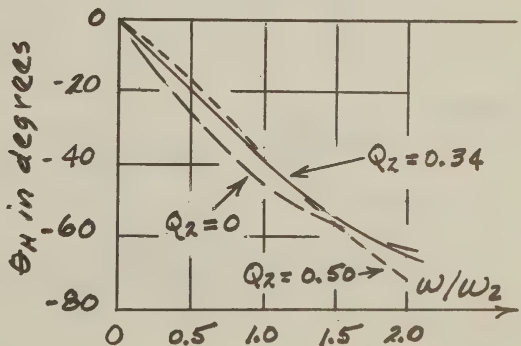
10.6

$\theta_H = \theta_0 - \theta_{p1} - \theta_{p2}$

θ_0 = zero angle

θ_{p1} = p_1 angle

θ_{p2} = p_2 angle



10.6 (Concl

Q_2	ω/ω_2	θ_0	θ_{p1}	θ_{p2}	θ_H
0.00	0.50				-26.6
0.00	1.00				-45.0
0.00	1.50				-56.3
0.00	2.00				-63.4
0.34	0.50	10	-14	43.5	-19.5
0.34	1.00	19.5	5	52.0	-37.5
0.34	1.50	28	23.5	58	-53.5
0.34	2.00	35	37	63	-65
0.50	0.50	13.5	-27	57	-16.5
0.50	1.00	27	0	65	-38
0.50	1.50	37.5	27	69	-55
0.50	2.00	46	46	72	-72

NOTE: $Q_2 = 0.34$ gives the most linear curve

10.7 Using Eq (10.31), the expression for $e_0(t)$ for a step function input is derived as follows:

$$E_0(s) = \frac{-g_m E_g}{s C_t}\left[\frac{s-p_0}{(s-p_1)(s-p_2)}\right]$$

$$= \frac{-g_m E_g}{C_t}\left[\frac{A}{s} + \frac{B}{s-p_1} + \frac{B_2}{s-p_2}\right]$$

where $$A = \frac{-p_0}{p_1 p_2} = \frac{2\alpha}{(-\alpha+j\beta)(-\alpha-j\beta)} = \frac{2\alpha}{\alpha^2+\beta^2}$$

$$B_1, B_2 = \frac{\alpha \pm j\beta}{\mp j2\beta(\alpha \mp j\beta)}$$ (B_1 & B_2 are complex conjugate

10.7 (Cont.)

Let $B_1, B_2 = a \pm jb = \dfrac{-\alpha}{(\alpha^2+\beta^2)} \pm j\dfrac{(\alpha^2-\beta^2)}{2\beta(\alpha^2+\beta^2)}$

$$e_o(t) = \frac{-g_m E_g}{C_t}\left[A + (a+jb)\epsilon^{\beta_1 t} + (a-jb)\epsilon^{\beta_2 t}\right]$$

$$= \frac{-g_m E_g}{C_t}\left[A + (2a \cos\beta t - 2b \sin\beta t)\epsilon^{-\alpha t}\right]$$

$$= \frac{-g_m E_g}{C_t}\left(\frac{2\alpha}{\alpha^2+\beta^2}\right)\left[1 - \epsilon^{-\alpha t}\cos\beta t - \frac{(\alpha^2-\beta^2)}{2\alpha\beta}\epsilon^{-\alpha t}\sin\beta t\right]$$

$$= -g_m R_b E_g\left[1 - \epsilon^{-\alpha t}\cos\beta t - \frac{(1-2Q_2)}{\sqrt{4Q_2-1}}\epsilon^{-\alpha t}\sin\beta t\right]$$

Note that for $Q_2 = 0.50$, the $\sin\beta t$ term drops out.

10.8 (a)

$$A_{vr} = [3000]^{1/3} = 14.4$$

$$A_{vr} = -g_m R \quad \text{and} \quad R = \frac{14.4}{9800 \times 10^{-6}} = 1.47 \times 10^3\ \Omega$$

$$C_T = C_{gk} + C_{pk} + C_w = 6.3 + 1.9 + 8 = 16.2\ pf$$

$$W_2 = \frac{1}{RC_T} = \frac{1}{1.47\times10^3 \times 16.2\times10^{-12}} = 42\times10^6\ r/s$$

$$f_2 = \frac{42\times10^6}{2\pi} = 6.68\ MHz$$

$$f_2(\text{required}) = 1.96\, f_{2(3)} = 1.96 \times 5.50 = 10.85\ MHz$$

∴ A high-frequency compensating network is required.

10.8 (Concl.) (b)

For $Q_2 = 0.50$: $\omega_2(\text{comp}) = 1.8\,\omega_2 = 1.8 \times 6.68 = 12.0$ M

" $Q_2 = 0.40$: $\omega_2(\text{comp}) = 1.7\,\omega_2 = 1.7 \times 6.68 = 11.35$ M

The overshoot is less than 2.5%.

For $Q_2 = 0.40$: $$L = \frac{Q_2 R_b}{\omega_2} = \frac{0.40 \times 1470}{2\pi \times 11.35 \times 10^6} = 8.25$$

10.9 (a)
$$\omega_1 = \frac{1}{(4.76 + 500)10^3 \times 0.01 \times 10^{-6}} = 198 \text{ r/s}$$
$$r_p \| R_b = \frac{5 \times 100}{105} = 4.76\ \text{K}\Omega$$

(b)
$$\omega_x = 2\pi(15) = 94.3 \text{ r/s}$$

$\omega_x + \omega_L = \omega_1$ and $\omega_L = 198 - 94.3 = 103.7$ r/s

$$C_x = \frac{1}{\omega_L R_b} = \frac{1}{103.7 \times 5000} = 1.93\,\mu f$$

$$R_x = \frac{1}{\omega_x C_x} = \frac{1}{94.3 \times 1.93 \times 10^{-6}} = 5500\,\Omega$$

(c)
$$E_{bb} = E_b + E_{kk} + (R_b + R_x) I_b$$
$$= 100 + 4 + (5 + 5.5)8 = 188 \text{ V}$$

10.10 (a) From Eq(10.42)

$$E_o(s) = \frac{A_{vr} E_g}{s}\left[\frac{s(s + \omega_x + \omega_L)}{(s+\omega_1)(s+\omega_x)}\right] = A_{vr} E_g \left[\frac{A}{s+\omega_1} + \frac{B}{s+\omega_x}\right]$$

10.10 (Concl.) where

$$A = \frac{\omega_x + \omega_L - \omega_1}{\omega_x - \omega_1} \quad \& \quad B = \frac{\omega_L}{\omega_1 - \omega_x}$$

$$e_o(t) = A_{vr} E_g \left[\frac{(\omega_x + \omega_L - \omega_1)}{\omega_x - \omega_1} \epsilon^{-\omega_1 t} - \frac{\omega_L}{\omega_x - \omega_1} \epsilon^{-\omega_x t} \right]$$

(b)

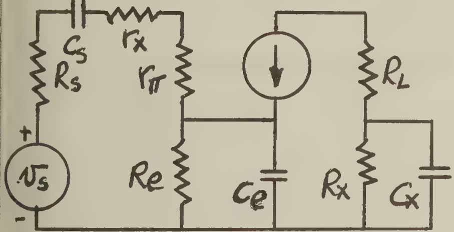
$$\frac{de_o}{dt} = A_{vr} E_g \left[-\omega_1 A \epsilon^{-\omega_1 t} - \omega_x B \epsilon^{-\omega_x t} \right]$$

At $t = 0$, $\frac{de_o}{dt} = 0$ when : $-\omega_1 A - \omega_x B = 0$

$$\omega_1 (\omega_x + \omega_L - \omega_1) - \omega_x \omega_L = 0$$

when $\omega_L = \omega_1$: $\omega_1 \omega_x - \omega_x \omega_L = 0$ & $\frac{de_o}{dt} = 0$

10.11 Let us add the compensating circuit to the simplified equivalent circuit of FIG. 8.15 (c).



The low frequency gain expression for the compensated circuit shown at the left is obtained by replacing R_L in Eq (8.83) with $z(s) = R_L + R_x \| 1/sC_x$.

$$z(s) = \frac{R_x}{sC_x \left[R_L + R_x + 1/sC_x \right]} + R_L = R_L + \frac{R_x \omega_x}{s + \omega_x}$$

10.11 (concl.) where $\omega_x = 1/R_x C_x$

$$Z(s) = R_L\left[\frac{s+\left(\frac{R_L+R_x}{R_L}\right)\omega_x}{s+\omega_x}\right] = R_L\left[\frac{s+\omega_{Lx}}{s+\omega_x}\right]$$

where $\omega_{Lx} = \left(\frac{R_L+R_x}{R_L}\right)\omega_x$

The low frequency gain $A_{vL}(s)$ for the compensated amplifier is

$$A_{vL}(s) = \frac{-\beta_0 R_L}{R_{ss}}\left[\frac{s(s+\omega_e)(s+\omega_{Lx})}{(s+\omega_m)(s+\omega_d)(s+\omega_x)}\right]$$

Substituting the numerical values listed on page 469, we obtain

$$A_{vL}(s) = A_{vr}\left[\frac{s(s+10)(s+\omega_{Lx})}{(s+2)(s+685)(s+\omega_x)}\right]$$

Let us assume we want ω_1 lowered from $\omega_d = 685$ r/s to $2\pi(30) = 189$ r/s.

$\omega_d = \omega_{Lx} = 685$ and $\omega_x = 2\pi(30) = 189$ r/s

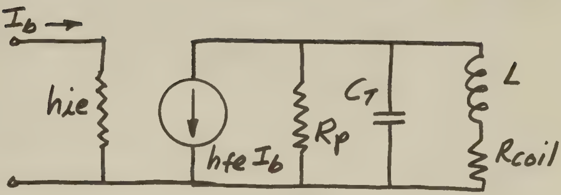
$$\left(\frac{R_L+R_x}{R_L}\right) = \frac{\omega_{Lx}}{\omega_x} = \frac{685}{189} = 3.62 \;\; \& \;\; R_x = 2620\ \Omega$$

$$C_x = \frac{1}{\omega_x R_x} = \frac{1}{189 \times 2620} = 2.02\ \mu f$$

NOTE THAT INSERTING R_x IN SERIES WITH R_L WITHOU[T] INCREASING V_{CC} REDUCES THE BIAS VALUES OF I_C AND V_{CE}. THE d-c LOAD LINE CONSISTS OF $R_L + R_x + R_e$, AS SHOWN IN FIG 10.7(b).

10.12 (a)

The single-tuned amplifier of FIG 10.9(a) can be represented by the circuit shown.



$$R_p = \frac{1}{h_{oe}} \| R_o = \frac{R_L}{1 + h_{oe} R_L}$$

$$R_T = R_p \| (1 + Q_{coil}^2) R_{coil} \doteq R_p \| Q_{coil}^2 R_{coil} \quad (Q_{coil} \gg 1)$$

Now $Q_p = \dfrac{R_p}{\omega_o L}$ or $R_p = \omega_o L Q_p$

So

$$R_T = \omega_o L Q_p \| Q_{coil}^2 R_{coil} = \omega_o L Q_p \| Q_{coil} \omega_o L$$

$$R_T = \omega_o L \left[\frac{Q_p Q_{coil}}{Q_p + Q_{coil}}\right]$$

$$Q_T = \frac{R_T}{\omega_o L} = \frac{Q_p Q_{coil}}{Q_p + Q_{coil}} \quad \text{and} \quad Q_p = \frac{Q_T\, Coil}{Q_{coil} - Q_T}$$

$$Q_T = \frac{\omega_o}{\omega_2 - \omega_1} = \frac{f_o}{f_2 - f_1} = \frac{455}{10} = 45.5$$

$$Q_p = \frac{100 \times 45.5}{100 - 45.5} = 83.5$$

$$R_p = \frac{1}{10 \times 10^{-6}} \| 10{,}000 = 9{,}100\,\Omega$$

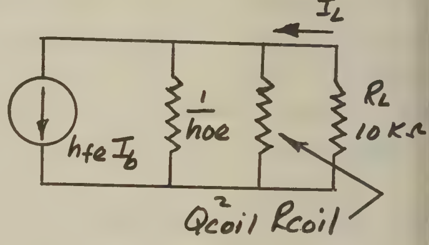
$$L = \frac{R_p}{\omega_o Q_p} = \frac{9100}{2\pi(455{,}000)(83.5)} = 38.1\,\mu h$$

$$C_T = \frac{1}{(2\pi \times 455{,}000)^2 (38.1 \times 10^{-6})} = 3210\,pf$$

10.12 (concl.) $C_{ext} = 3210 - 20 = 3190\ pf$

$$R_{coil} = \frac{\omega_0 L}{Q_{coil}} = \frac{2\pi(455\times10^{6})(38.1\times10^{-6})}{100} = 1.09\ \Omega$$

$$Q_{coil}^2 R_{coil} = (100)^2(1.09) = 10.90\ K\Omega$$



$$R_1 = \frac{1}{hoe} \,\|\, Q_{coil}^2 R_{coil}$$

$$= 100 \,\|\, 10.9 = 9.85\ k\Omega$$

$$A_i = \frac{I_L}{I_b} = \frac{R_1 h_{fe}}{R_1 + R_L} = \frac{9.85\times100}{9.85+10} = 49.5$$

$$A_v = \frac{V_L}{V_s} = \frac{-R_L A_i}{R_s + h_{ie}} = \frac{-10\times49.5}{1+3} = -124$$

(c) Yes, because $Q_{coil}^2 R_{coil} = 10.9\ K\Omega$ is essentially the same as $R_L = 10\ K\Omega$. It reduces A_i by approximately 2.

10.13 (a) The solution of this problem is quite similiar to that of PROB. 10.12.

$$Q_T = \frac{R_T}{\omega_0 L} = \frac{Q_{coil} Q_p}{Q_{coil} + Q_p} = \frac{f_0}{f_2 - f_1} = \frac{455}{10} = 45.5$$

$$Q_p = \frac{100\times45.5}{100-45.5} = 83.5$$

$$R_p = r_p \,\|\, R_L = \frac{250\times200}{250+200} = 111\ K\Omega$$

$$L = \frac{111\times10^3}{2\pi\times.455\times10^6\times83.5} = 465\ \mu h$$

10.13 (Concl.)

$$R_{coil} = \frac{2\pi(.455\times10^6)(465\times10^{-6})}{100} = 13.30$$

$$C_T = \frac{1}{(2\pi\times.455\times10^6)^2(465\times10^{-6})} = 263\ pf$$

$$C_{ext} = 263 - 5.5 - 10 = 247\ pf$$

$$R_T = R_p \| Q_{coil}^2 R_{coil} = 111\|(100)^2(13.30) = 111\|133 = 60.5\ k\Omega$$

$$A_{vr} = -g_m R_T = -3500\times60.5\times10^3 = -212$$

(b) Yes, because $Q_{coil}^2 R_{coil} = 133\ k\Omega$ and the load $R_L = 200\ k\Omega$.

10.14 At $\omega = \omega_1$ the denominator of Eq (10.58) has equal real and j-terms.

$$\omega_1\left[\frac{L_2}{R_0} + R_2 C_2\right] = \left[1 - \omega_1^2 L_2 C_2\right]$$

$$\omega_1\left[\frac{\omega_0 L_2}{\omega_0 R_0} + \frac{R_2}{\omega_0^2 L_2}\right] = 1 - \frac{\omega_1^2}{\omega_0^2} \quad ; \quad \omega_0^2 = \frac{1}{L_2 C_2}$$

$$\omega_1\left[\frac{1}{\omega_0 Q_0} + \frac{1}{\omega_0 Q_{coil}}\right] = 1 - \frac{\omega_1^2}{\omega_0^2}$$

$$\frac{\omega_1}{\omega_0}\left[\frac{Q_{coil} + Q_0}{Q_0\, Q_{coil}}\right] = \frac{\omega_1}{\omega_0 Q_e} = 1 - \frac{\omega_1^2}{\omega_0^2}$$

In a similiar manner

$$\frac{\omega_2}{\omega_0 Q_e} = \frac{\omega_2^2}{\omega_0^2} - 1$$

10.14 (Concl.)

$$\frac{\omega_2}{\omega_0 Q_e} + \frac{\omega_1}{\omega_0 Q_e} = \frac{\omega_2^2 - \omega_1^2}{\omega_0^2}$$

$$\frac{\omega_2 + \omega_1}{Q_e} = \frac{(\omega_2+\omega_1)(\omega_2-\omega_1)}{\omega_0}$$

$$Q_e = \frac{\omega_0}{\omega_2 - \omega_1}$$

10.15 Correction: The transistor parameters are given in PROB 10.12 and not in Prob 10.14.

(a)

The circuit of the amplifier is given in Fig 10.9

$$Q_e = \frac{Q_0 Q_{coil}}{Q_{coil} - Q_0} = \frac{\omega_0}{\omega_2 - \omega_1} = \frac{455}{10} = 45.5$$

$$Q_0 = \frac{R_0}{\omega_0 L_2} = \frac{Q_e Q_{coil}}{Q_{coil} - Q_e} = \frac{45.5 \times 100}{100 - 45.5} = 83.3$$

$$L_2 = \frac{R_0}{\omega_0 Q_0} = \frac{3000}{2\pi \times .455 \times 10^6 \times 83.3} = 12.6 \mu h$$

$$C_2 = \frac{1}{(2\pi \times .455 \times 10^6)^2 (12.6)} = 9700 pf$$

$$R_2 = \frac{2\pi \times .455 \times 10^6 \times 12.6 \times 10^{-6}}{100} = 0.36 \Omega$$

(b) $g_m = 0.0385$ ℧ ; $r_\pi = \dfrac{100}{0.0385} = 2600 \Omega$

$r_x = 3000 - 2600 = 400 \Omega$

10.15 (concl.) $V_\pi = \dfrac{r_\pi V_{be}}{h_{ie}} = \dfrac{2600\, V_{be}}{3000} = 0.867\, V_{be}$

$$V_o = \omega_o M g_m Q_e V_\pi = \omega_o M g_m Q_e (0.867) V_{be}$$

$$A_{vr} = \frac{V_o}{V_{be}} = 2\pi \times .455 \times 10^6 \times 0.0385 \times 45.5 \times 0.867\, M$$

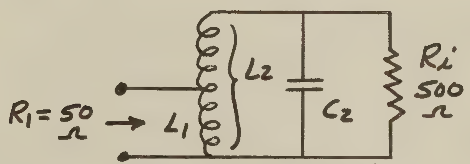
$$M = \frac{A_{vr}}{4.35 \times 10^6} = \frac{50}{4.35 \times 10^6} = 11.55\,\mu h$$

(c) Assume $k = 1.00$, $M = k\sqrt{L_1 L_2}$

$$L_1 = \frac{M^2}{k^2 L_2} = \frac{(11.55 \times 10^{-6})^2}{(1)^2 (12.6 \times 10^{-6})} = 10.55\,\mu h$$

10.16

$$Q_o = \frac{\omega_o}{B} = \frac{f_o}{B_H}$$



$$Q_o = \frac{1 \times 10^6}{20 \times 10^3} = 50$$

$$\frac{R_1}{R_i} = \frac{L_1}{L_2} = \left[\frac{n_1}{n_2}\right]^{1/2}$$

$$L_2 = \frac{R_i}{\omega_o Q_o} = \frac{500}{2\pi \times 10^6 \times 50} = 1.59\,\mu h \; ; \; L_1 = \frac{50}{500} L_2 = 0.159\,\mu h$$

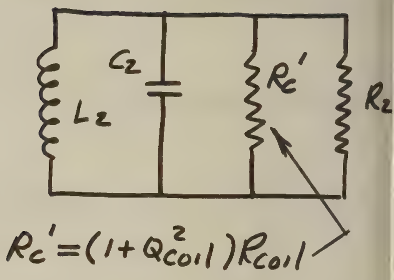
$$C_2 = \frac{1}{(2\pi \times 10^6)^2\, 1.59 \times 10^{-6}} = 15{,}900\, pf$$

Center tapping 500 Ω load on load side of L_2 makes

$$L_2 = 2 \times 1.59 = 3.18\,\mu h$$

$$C_2 = \frac{15{,}900}{2} = 7950\, pf$$

10.17



$$Q_2 = \omega_0 C_2 R_2$$

$$R_2 = \frac{Q_2}{\omega_0 C_2}$$

$$Q_{coil} = \frac{\omega_0 L_2}{R_{coil}} = \omega_0 C_2 R_c'$$

$$R_c' = \frac{Q_{coil}}{\omega_0 C_2}$$

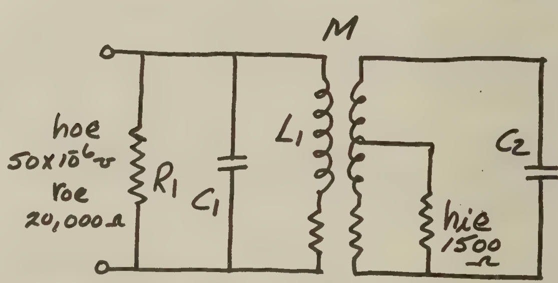
$$R = R_c' \| R_2 = \frac{Q_2 Q_{coil}}{(\omega_0 C_2)^2} \cdot \frac{1}{\frac{Q_2}{\omega_0 C_2} + \frac{Q_{coil}}{\omega_0 C_2}}$$

$$R = \frac{1}{\omega_0 C_2}\left[\frac{Q_2 Q_{coil}}{Q_2 + Q_{coil}}\right]$$

$$Q = \omega_0 C_2 R = \frac{Q_2 Q_{coil}}{Q_2 + Q_{coil}}$$

10.18

$f_0 = 455\ kHz$
$B_H = 20\ kHz$



$$\omega_0 = 2\pi \times 0.455 \times 10^6 = 2.860 \times 10^6\ r/s\ ;\ B = 125.7 \times 10^3\ r/s$$

$$Q = \frac{Q_2 Q_{coil}}{Q_2 + Q_{coil}} = \frac{100 \times 150}{100 + 150} = 60$$

$$\frac{\omega_0}{Q} = \frac{2.860 \times 10^6}{60} = 47.6 \times 10^3\ r/s$$

<u>10.18</u> (concl.) Applying Eq(10.82), we obtain

$$kW_0 = -47.6\times10^3 \pm \left[2(2270\times10^6)+(15{,}800)\right]^{1/2}$$

$$= -47.6\times10^3 \pm 141\times10^3 = 93.4\times10^3$$

$$k = \frac{93.4\times10^3}{2{,}860\times10^6} = 0.0327$$

$$k_c = \frac{1}{Q} = \frac{1}{60} = 0.0167 \; ; \; \therefore \; k > k_c$$

$$Q_1 = Q_2 = W_0 C_1 R_1 = \frac{R_1}{W_0 L_1} \; ; \; L_1 = \frac{20{,}000}{2.860\times10^6\times100} = 69.80 \; \mu h$$

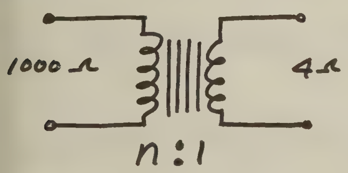
$$C_1 = \frac{Q_1}{W_0 R_1} = \frac{100}{2.860\times10^6\times20{,}000} = 1750 \; pf$$

$L_1 = L_2 = 69.80\,\mu h$ and $C_1 = C_2 = 1750\,pf$

L_2 tapped at $\frac{1500\times69.80}{20{,}000} = 5.25\,\mu h$

$$n_{tap} = n_2\sqrt{\frac{1500}{20{,}000}} = 0.274\, n_2$$ turns from bottom of L_2

<u>10.19</u>



$$n = \left[\frac{1000}{4}\right]^{1/2} = 15.8$$

$$L_m = \frac{R}{W_1} = \frac{1000\|1000}{2\pi\times30} = 2.65 \text{ henries}$$

$$L_1 \doteq L_m = 2.65 \text{ henries}$$

10.19 (concl.)

$$L_2 = \frac{L_1}{n^2} = \frac{2.65}{(15.8)^2} = 10.6 \text{ mh}$$

$$\omega_2 = 2\pi \times 20{,}000 = 125{,}700 \text{ r/s}$$

$$L_L = \frac{R_o + n^2 R_i}{\omega_2} = \frac{1000+1000}{125{,}700} = 0.0159 \text{ henries}$$

$$k = \frac{2L_1 - L_L}{2L_1} = 1 - \frac{L_L}{2L_1} = 1 - \frac{0.0159}{5.30} = 1 - 0.003$$

$$k = 0.997$$

CHAPTER 11

11.1 (a) From Fig 11.4, $V_{sm} = 0.74$ V

$$I_{b1m} = \frac{60-7}{2} = 26.5 \text{ ma}; \quad I_{b2m} = \frac{60+7-2(30)}{4} = 1.75 \text{ ma}$$

$$P_{s1} = \frac{V_{sm} I_{b1m}}{2} = \frac{0.74 \times 26.5 \times 10^{-3}}{2} = 9.8 \text{ mw}$$

(b) $$I_{c1m} = \frac{(3.9-0.90)+(3.09-1.63)}{3} = 1.485 \text{ a}$$

$$P_o = \frac{R_{ac} I_{c1m}^2}{2} = \frac{4.5(1.485)^2}{2} = 5.00 \text{ W}$$

$$G = \frac{5.00}{9.8 \times 10^{-3}} = 510; \quad G_{db} = 10 \log 510 = 27 \text{ db}$$

(c) $$I_{c3m} = \frac{(3.9-0.90)-2(3.09-1.63)}{6} = \frac{3.0-2.92}{6} = 0.0133 \text{ a}$$

11.1 (concl.)

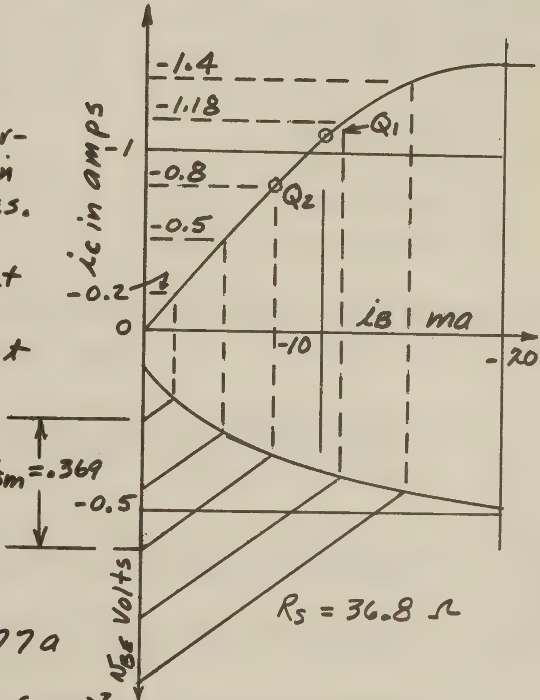
$$\% \; 3^{rd} = \frac{0.0133 \times 100}{1.485} = 0.90\,\%$$

(d) There is no 2^{nd} harmonic in the output, so

$$P_{CC} = V_{CC} I_C = V_{CE} I_C = (-8)(-2.4) = 19.2 \text{ w}$$

11.2

The input and the transfer characteristics are shown in the adjacent curves.



For a base current of

$$i_B = -10 - 10 \sin \omega t$$

we have

$$i_{C(max)} = -1.54 \text{ a}$$
$$i_{C(min)} = 0$$
$$I_C = -1.10 \text{ a}$$

$$I_{c1m} = \frac{1.54 - 0}{2} = 0.77 \text{ a}$$

$$P_o = \frac{R_{oc} I_{c1m}^2}{2} = \frac{15(0.77)^2}{2} = 4.45 \text{ W}$$

$$I_{c2m} = \frac{1.54 + 0 - 2(1.10)}{4} = \frac{1.54 - 2.20}{4} = -0.165 \text{ a}$$

$$\% \; 2^{nd} = \frac{0.165 \times 100}{0.77} = 21.4\,\%$$

11.2 (Concl.)

Since this Q-point (see Q_1 on curves) is not centered in the i_C vs i_B characteristic, let us move it down to Q_2 where the values are:

$$I_C = -0.80\text{ a} \; ; \; I_B = -7.2\text{ ma} \; ; \; V_{BE} = -0.35\text{ v}$$

Now let us eliminate the second harmonic by making the positive and the negative swings of i_C about $I_C = -0.80$ a equal, i.e.,

i_B	v_{BE}	i_C
-14.5	-0.45	-1.4
-7.2	-0.35	-0.8
-1.8	-0.18	-0.20

Substituting these values into Eq(11.2), we can determine the value of R_S.

$$R_S = \frac{2(0.35)-[0.45+0.18]}{14.5+1.8-2(7.2)} = \frac{0.70-0.63}{16.3-14.4} = 0.0368\text{ K}\Omega$$

Using Eq(11.1), we can determine V_{sm}.

$$V_{sm} = 0.0368[14.5-7.2]+[0.45-0.35]$$

$$= 0.0368(7.3)+0.10 = 0.369\text{ V}$$

$$I_{c1m} = \frac{[1.40-0.20]+(1.18-0.50)}{3} = \frac{1.20+0.68}{3} = 0.626\text{ a}$$

$$I_{c3m} = \frac{[1.40-0.20]-2[1.18-0.50]}{6} = \frac{1.20-1.36}{6} = -0.027\text{ a}$$

$$\%\,3^{d} = \frac{0.027\times 100}{0.626} = 4.3\,\% \; ; \; P_o = \frac{(.626)^2(15)}{2} = 2.94\text{ W}$$

11.3 (a) when $e_{c1} = 0$, $e_{c2} = -50\text{ V}$ and $i_{b2} = 0$.

The composite characteristic for $e_{c1} = 0$ and $e_{c2} = -50\text{ v}$ is the same as the characteristic for $e_{c1} = 0$.

$$P_o = \left[\frac{i_{b1}(max) - i_{b2}(min)}{2}\right]^2 \frac{R_{pp}}{2}$$

$$= \left[\frac{0.127 - 0.00}{2}\right]^2 \frac{10{,}000}{2} = 20.2\ W$$

(b)
$$P_{bb} = 2E_{bb}[I_b + I_{p2m}]$$

$$I_{p2m} = \frac{127 + 0 - 2(22)}{4} = \frac{83}{4} = 20.75\ ma$$

$$P_{bb} = 2 \times 350\,[22 + 20.75]10^{-3} = 29.9\ w$$

(c)
$$\eta_p = \frac{P_o}{P_{bb}} \times 100 = \frac{20.2 \times 100}{29.9} = 67.5\ \%$$

(d)
$$I_s = \frac{i_{b1}(max) - i_{b2}(min)}{2a} \ ; \quad a = \left[\frac{8}{10{,}000}\right]^{1/2} = 2.83 \times 10^{-2}$$

$$I_s = \frac{(127 - 0)10^{-3}}{2 \times 2.83 \times 10^{-2}} = 2.24\ a$$

(e)
$$I_{p3m} = \frac{(127 - 0) - 2(77 - 3)}{6} = \frac{127 - 148}{6} = -3.5\ ma$$

$$I_{p1m} = \frac{127 - 0}{2} = 63.5\ ma \ ; \quad \%\,3^{d} = \frac{3.5 \times 100}{63.5} = 5.5$$

(f) Similiar to dynamic characteristic shown in Fig 11.6.

11.4 $E_{cc} = -30V$; $e_{gg} = 50 \sin \omega t$

$e_{c1} = -30 + 25 \sin \omega t$; $e_{c1(max)} = -5\ V$

$e_{c2} = -30 - 25 \sin \omega t$; $e_{c1}(min) = -55\ V$

$i_{b1}(max) = 120\ ma$; $i_{b2}(min) = 0$

$$P_o = \left[\frac{0.120 - 0}{\sqrt{2}}\right]^2 \frac{10{,}000}{4} = 18\ W$$

$$I_{C3m} = \frac{[120-0] - 2[52-0]}{6} = 2.67\ ma$$

$$I_{c1m} = \frac{120-0}{2} = 60\ ma$$

$$\%\ 3^{d} = \frac{2.67 \times 100}{60} = 4.45\%$$

There is slight reduction in % 3^{d} harmoni[c] since operation is taken out of the knee region. There is, however, a 10% reductio[n] in output power.

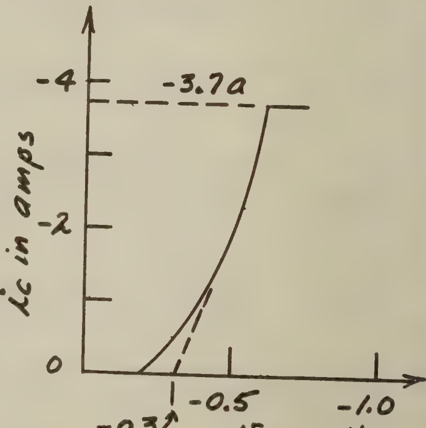
11.5 (a) & (b)

Cutoff occurs at:

$V_{BE} \doteq -0.14\ V$; $I_c = 0$

$$P_o = \frac{(3.70 - 0)^2 (12)}{8}$$

$P_o = 20.5\ W$



11.5 (Concl)

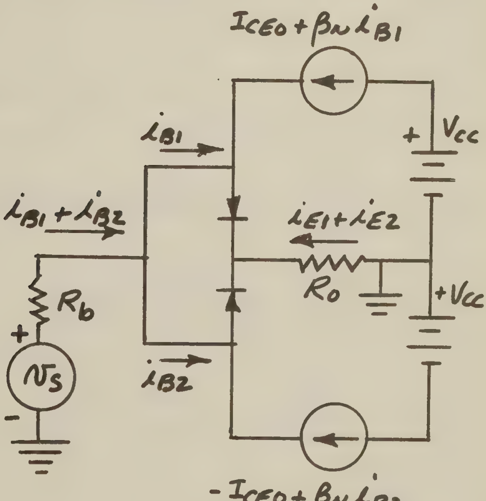
Waveform of $(i_{C1} - i_{C2})$ vs time is similiar to that shown in Fig 11.8(b) for Class B operation of vacuum tubes. The curvature in the i_C vs v_{BE} dynamic characteristic in the vicinity of cutoff produces 3rd harmonic distortion

(c) Let us use a projected cutoff of

$$V_{BE} \doteq -0.30\,V \;;\; I_B \doteq -5\,ma \;;\; I_C = -0.50\,a$$

The dotted line in the i_C vs v_{BE} characteristic shows the improvement in linearity obtained by operating at the above quiescent point. The waveform of $(i_{C1} - i_{C2})$ vs time is similiar to the waveform of $(i_{b1} - i_{b2})$ shown in Fig 11.8(a) for Class AB operation of vacuum tubes.

11.6 (a)



$$i_{C1} = I_{CEO} + \beta_N i_{B1}$$

$$i_{C2} = -I_{CEO} + \beta_N i_{B2}$$

For $v_S = 0$:

$$I_{B1} + I_{B2} = 0$$

$$I_{E1} + I_{E2} = 0$$

$$V_{CC} - V_{CE1} + R_o(I_{E1} + I_{E2}) = 0$$

$$\therefore V_{CE1} = V_{CC} \;\&\; V_{CE2} = -V_{CC}$$

11.6 (Concl.)

$$v_S - R_b(I_{b1} + I_{b2}) - V_{BE1} + R_o(I_{E1} + I_{E2}) = 0$$

$\therefore$ $V_{BE1} = 0$ & $V_{BE2} = 0$ when $v_S = 0$.

$$I_{C1} = -I_{C2} = I_{CEO} = \frac{I_{CO}}{1-\alpha_N} = \frac{1}{1-0.98} = 50\,\mu a$$

The circuit is operating Class B.

(b) For small positive value of v_S, T_2 is cutof and T_1 operates in the amplification state.

$$v_S = (R_b + R_o) i_{B1} + R_o i_{C1} = (R_b + R_o + \beta_N R_o) i_{B1}$$

$$i_{B1} = \frac{v_S}{R_b + (1+\beta_N)R_o}$$

$$v_o = R_o i_{E1} = R_o(1+\beta_N) i_{B1} = \frac{R_o(1+\beta_N)v_S}{R_b + (1+\beta_N)R_o} \doteq v_S$$

$$A_v = \frac{v_o}{v_S} \doteq 1 \quad (\text{For } (1+\beta_N)R_o \gg R_b)$$

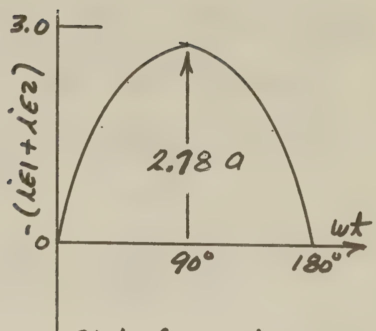
$$A_i = \frac{i_{e1}}{i_{b1}} = (1+\beta_N) = 1 + 49 = 50$$

$$G = \frac{P_o}{P_i} = A_v A_i = 50$$

11.7

(a) The transistors are operating Class B. On the positive half-cycle the currents in T_2 are:

ωt	i_{B2}	i_{C2}	i_{E2}
0	0	0	0
14.5°	10	1.05	-1.06
30°	20	1.62	-1.64
48.6°	30	2.22	-2.25
90°	40	2.74	-2.78



Plot of positive half-cycle of $-(i_{E1}+i_{E2}) = -i_{E2}$.

$$P_o = \frac{I_{e1m}^2 R_L}{2} = \frac{4\, I_{e1m}^2}{2} = 15\,W$$

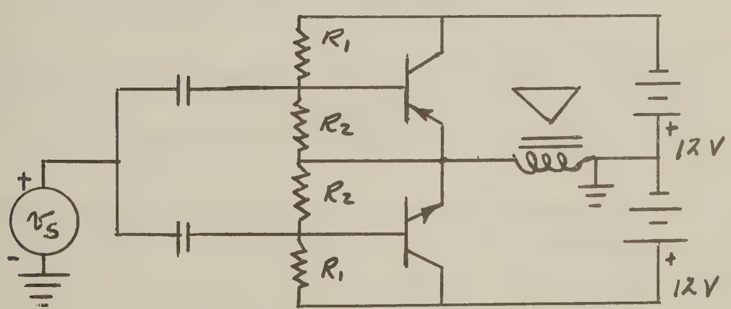
$$I_{e1m} = i_{E1}(max) = \sqrt{\frac{30}{4}} = 2.74\ a$$

From load line

$$i_B(max) = 40\ ma\ ; \quad i_C(max) = 2.74\ a$$

$$i_E(max) = 2.74 + 0.04 = 2.78\ a$$

(b)



11.7 (Concl.) (b) Assume $R_b = 4\,\Omega$

$$V_{BB} = R_b I_B + V_{BE} = 4(0.005) + 0.18 = 0.20\ \text{V}$$

$$R_1 = \frac{R_b V_{CC}}{V_{BB}} = \frac{4 \times 12}{0.20} = 240\,\Omega$$

$$R_2 = \frac{R_1 R_b}{R_1 - R_b} = \frac{240 \times 4}{240 - 4} = 4.07\,\Omega$$

(c) This change in the grounding point converts the amplifier circuit from a common collector to a common emitter. Since the latter has a voltage gain much greater than unity, it requires a correspondingly lower value of v_3.

11.8

$i_c(max) = 2.8$ a, $R_L = 4\,\Omega$ (Text page 612)

$$P_o \doteq \left[\frac{i_c(max)}{\sqrt{2}}\right]^2 R_L = \left[\frac{2.8}{\sqrt{2}}\right]^2 (4) = 15.7\ \text{W}$$

$$V_{BB} = \frac{3.90 \times 18}{3.90 + 390} = 0.18\ \text{V}\ ;\ h_{FE} \doteq 100$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B + (1+\beta_o) R_E} = \frac{0.18 - 0.17}{3.9 + 100(0.33)} = \frac{0.01}{3.9 + 33}$$

$I_B = 0.271$ ma ; $I_C = h_{FE} I_B = 100 \times 0.271 = 27$ ma

$2\,I_C\,(\text{Pair}) = 2 \times 0.027 = 0.054$ a

This is as far as we can go with the data we have.

11.9 $e_{gg} = 50 \sin \omega t$ (From Prob 11.3)

$$\left.\begin{aligned} e_{o1} &= 25 \sin \omega t \\ e_{o2} &= -25 \sin \omega t \end{aligned}\right\} \text{see Fig 11.14}$$

Required voltage gain $= \dfrac{e_{o1}}{e_s} = \dfrac{25}{0.50} = 50$

Let us use the 12AX7 (Appendix A.14) which is a dual triode with a $\mu = 100$ and $r_p = 77\ K\Omega$ for $I_b = 0.80$ ma and $E_b = 170$ V.

$$A_v = 50 = \frac{\mu R_b}{r_p + R_b} = \frac{100 R_b}{77 + R_b} = \frac{100 \times 100}{77 + 100}$$

$= 56.5$ (This is borderline)

Let us use $R_b = 200\ K\Omega$ and $E_{bb} = 250$ V, and select a Q point at

$$I_b = 0.50 \text{ ma}; \quad E_c = -1.5 \text{ V}; \quad E_b = 150 \text{ V}$$

$$R_K = \frac{1.5}{0.50} = 3.0\ K\Omega$$

Use an $R_g = 1\ M\Omega$ and $R_1 = 1\ M\Omega$.

Revised ckt gain $= \dfrac{100 \times 200}{77 + 200} = 72.2$

$$\frac{R_2}{R_1 + R_2} = \frac{1}{A_v} \quad \text{or} \quad R_2 = \frac{R_1}{A_v - 1} = \frac{1000}{72.2 - 1} = 14.0\ K\Omega$$

11.10 From Eq (11.26)

$$e_c = E_{cc} + E_{gm}\cos\omega_p t\ ; \quad \cos\omega_p t = \frac{e_c - E_{cc}}{E_{gm}}$$

$$e_b = E_{bb} - E_{pm}\cos\omega_p t = E_{bb} - \frac{(e_c - E_{cc})E_{pm}}{E_{gm}}$$

$$e_b = (E_{bb} - \mu E_{cc}) + \mu e_c$$

where $\mu = -\dfrac{E_{pm}}{E_{gm}}$

11.11 Starting with Eq (11.31), we have

$$I_{p1m} = \frac{2}{\pi}\int_0^{\pi} i_b \cos\omega_p t \, d(\omega_p t)$$

$$= \frac{2}{\pi}\cdot\frac{\pi}{12}\left[\frac{A}{2} + B\cos 15^\circ + C\cos 30^\circ + D\cos 45^\circ + E\cos 60^\circ + F\cos 75^\circ + G\cos 90^\circ\right]$$

$$= \frac{1}{12}\left[A + 1.93B + 1.73C + 1.41D + E + 0.52F + 0\right]$$

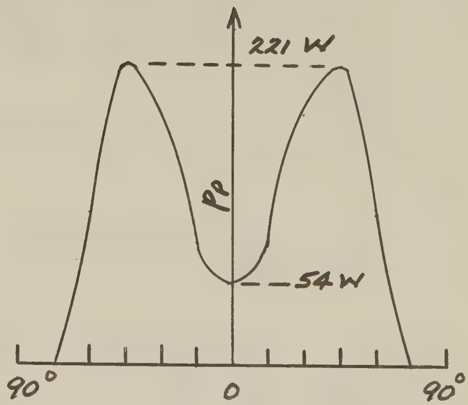
$$I_{p2m} = \frac{2}{\pi}\int_0^{\pi} i_b \cos 2\omega_p t \, d(\omega_p t)$$

$$= \frac{2}{\pi}\cdot\frac{\pi}{12}\left[\frac{A}{2} + B\cos 30^\circ + C\cos 60^\circ + D\cos 90^\circ + E\cos 120^\circ + F\cos 150^\circ\right]$$

$$= \frac{1}{12}\left[A + 1.73B + C + 0 - E - 1.73F\right]$$

11.12 From the data on page 627,

e_b	i_b	P_p
120	450	54
185	460	85
370	470	174
670	330	221
1060	100	106
1514	0	0
2000	0	0



$$P_p = \frac{1}{12}\left[\frac{54}{2} + 85 + 174 + 221 + 106 + 0 + 0\right] = \frac{613}{12}$$

$P_p = 51$ W (checks value on page 628)

11.13 (a) & (b)

$\omega_p t$	e_b	e_c	i_b	i_c	I_b	I_c	I_{p2m}	I_{g1m}
0	120	100	450	100	225	50	450	100
15	370	92	550	82	550	82	950	160
30	1060	69	570	55	570	55	570	95
45	2000	33	385	22	385	22	0	31
60	2940	-15	160	0	160	0	-160	0
75	3630	-70	10	0	10	0	-17	0
90	3880	-130	0	0	0	0	0	0
					1900	209	1793	386

$I_b = 160$ $\qquad I_c = 17.5$

$I_{p2m} = 149$ $\qquad I_{g1m} = 32.2$

(c) $R_p = \frac{1880}{0.149} = 12{,}600\ \Omega$

11.13 (concl.) (d)

$$P_L = \frac{1880 \times 0.149}{2} = 140 \text{ W}$$

$$P_{bb} = 2000 \times 0.160 = 320 \text{ W}$$

$$P_p = 320 - 140 = 180 \text{ W}$$ (Max is 65 W; θ_b must be reduced)

$$\eta_p = \frac{140}{320} = 43.7\%$$

(e) $$P_{in} = \frac{230 \times 0.0322}{2} = 3.80 \text{ W}$$

$$P_{cc} = 130 \times 0.0175 = 2.28 \text{ W}$$

$$P_g = 3.80 - 2.28 = 1.52 \text{ W}$$

(f) $$R_b = \frac{12{,}600}{1+(15)^2} = 55.8\ \Omega \ ; \ L_b = \frac{15 \times 55.8}{2\pi \times 28} = 4.7 \ \mu h$$

$$C_b = \frac{L_b}{R_b R_p} = \frac{4.75 \times 10^{-6}}{55.8 \times 12{,}600} = 6.75 \text{ pf}$$

11.14

$$E_p = (R_{coil} + j\omega_p L_b) I_T + j\omega_p M I_s$$

$$0 = j\omega_p M I_T + (R_s + R_a + jX_s) I_s$$

where $$X_s = \omega_p L_s - \frac{1}{\omega_p C_s}$$

Solving these two equations for I_T, we get

$$Z_b = \frac{E_p}{I_T} = R_{coil} + j\omega_p L_b + \frac{(\omega_p M)^2}{R_s + R_a + jX_s}$$

11.15 (a)

$$Z_{bc} = \frac{-jX_M R_o}{R_o - jX_m} = \frac{R_o X_M^2 - jR_o^2 X_M}{R_o^2 + X_M^2}$$

where $X_M = \dfrac{1}{\omega_p C_M}$

(b) From Sections 11.12 and 11.13,

$f_p = 14\ MHz$; $R_b = 36.8\ \Omega$

$R_{bc} = R_b - R_{coil} = 36.8 - 2.8 = 34\ \Omega$ $\left(\begin{array}{l}\text{Transformed} \\ \text{value of } 50\ \Omega \\ \text{coax cable}\end{array}\right)$

$$R_{bc} = \frac{R_o X_M^2}{R_o^2 + X_M^2} \quad \text{or} \quad X_M = \left[\frac{R_{bc} R_o^2}{R_o - R_{bc}}\right]$$

$$X_m = \left[\frac{34(50)^2}{50-34}\right]^{1/2} = 50\sqrt{\frac{34}{16}} = 73\ \Omega$$

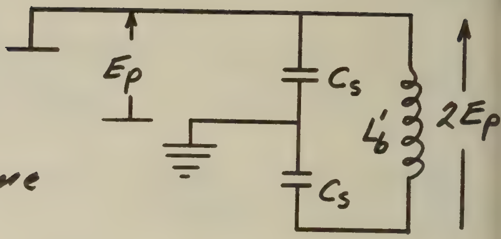
$$C_M = \frac{1}{\omega_p X_M} = \frac{1}{2\pi \times 14 \times 10^6 \times 73} = 155\ pf$$

$$X_{bc} = \frac{X_M R_o^2}{R_o^2 + X_m^2} = \frac{X_M}{1 + \left(\frac{X_M}{R_o}\right)^2} = \frac{73}{1 + \left(\frac{73}{50}\right)^2} = 23.3\ \Omega$$

$$\omega_p L_b' = \omega_p L_b + X_{bc} \quad \text{or} \quad L_b' = L_b + \frac{X_{bc}}{\omega_p}$$

$$L_b' = 6.28 + \frac{23.3}{2\pi \times 14 \times 10^6} = 6.28 + 0.265 = 6.54\ \mu h$$

11.16



$$C_b' = \frac{C_s}{2}$$

The circuit Q is to remain the same so

$$Q_b = \frac{R_p}{\omega_p L_b} = \omega_p C_b R_p$$

Effective resistance R_p' across L_b' is $4R_p$, so

$$Q_b = \frac{R_p'}{\omega_p L_b'} = \omega_p C_b' R_p'$$

$$C_b' = \frac{Q_b}{\omega_p R_p'} = \frac{Q_b}{4\omega_p R_p}$$

$$\therefore\ C_b' = \frac{C_b}{4} \quad \text{and} \quad C_s = 2C_b' = \frac{C_b}{2} = \frac{20.6}{2} = 10.3\ p\text{[illegible]}$$

Now $C_b L_b = C_b' L_b'$ so $L_b' = 4L_b = 4 \times 6.28 = 25.12$ μh

11.17

Let us use a prime to designate the symbols for the two tubes connected in parallel. Since $I_{pim}' = 2I_{pim}$ & $I_c' = 2I_c$, we ge[t]

$$R_p' = \frac{E_{pm}}{2I_{pim}} = \frac{R_p}{2}\ ; \quad R_b' = \frac{R_p'}{1+Q_b^2} = \frac{R_b}{2}$$

$$L_b' = \frac{Q_b R_b'}{\omega_p} = \frac{Q_b R_b}{2\omega_p} = \frac{L_b}{2}\ ; \quad C_b' = \frac{L_b'}{R_b' R_p'} = 2C_b$$

$$E_{cc} = R_c' I_c' = R_c'(2I_c)\ ; \quad R_c' = \frac{R_c}{2}$$
$$= R_c I_c$$

11.18

$$Z_m = \frac{-jX_3(R_L - jX_4)}{R_L - j(X_3+X_4)} \cdot \frac{R_L + j(X_3+X_4)}{R_L + j(X_3+X_4)}$$

$$= \frac{(-jX_3R_L - X_3X_4)[R_L + j(X_3+X_4)]}{R_L^2 + (X_3+X_4)^2}$$

$$= \frac{X_3^2R_L - jX_3[R_L^2 + X_4(X_3+X_4)]}{R_L^2 + (X_3+X_4)^2} \qquad (11.53)$$

11.19

From Eq (11.53),

$$R_m = r_{os} = \frac{X_3^2R_L}{R_L^2 + (X_3+X_4)^2} \doteq \frac{X_3^2R_L}{(X_3+X_4)^2}$$

$$X_3 \doteq (X_3+X_4)\sqrt{\frac{R_m}{R_L}} = a(X_3+X_4)$$

Correction: Add $\sqrt{\ }$ to expression for a in Eq (11.54)

$$X_4 \doteq \left(\frac{1-a}{a}\right)X_3 = k X_3$$

where $a = \sqrt{\frac{R_m}{R_L}}$ and $k = \frac{(1-a)}{a}$

$$X_m = \frac{X_3[R_L^2 + X_4(X_3+X_4)]}{R_L^2 + (X_3+X_4)^2} \doteq \frac{X_3X_4}{X_3+X_4} = \frac{kX_3}{1+k}$$

$$X_3 \doteq \frac{(1+k)X_m}{k} = \frac{X_m}{1-a}$$

$$a = \sqrt{\frac{4.81}{50}} = 0.31 \; ; \quad k = \frac{(1-0.31)}{0.31} = 2.23$$

$$X_3 = \frac{67.3}{1-0.31} = 97.5\,\Omega \; ; \; X_4 = 2.23 \times 97.5 = 217\,\Omega$$

$$C_3 = \frac{1}{2\pi(150\times10^6)(97.5)} = 10.9\text{ pf} ; \; C_4 = \frac{1}{2\pi(150\times10^6)(217)}$$

$$C_4 = 4.9\text{ pf}$$

11.20 (a) When the plate circuit is detuned, the plate voltage minimum $e_b(min)$ does not occur at the same time as $e_c(max)$, i.e., the waveform of e_b in Fig 11.16 is shifted. This causes i_b to increase resulting in a much larger increase in plate dissipation and a corresponding decrease in plate efficiency.

(b) Since the area under the plate current pulse is a minimum when $e_b(min)$ and $e_c(max)$ occur at the same time, the average plate current I_b is a minimum at resonance. The grid current pulse, on the other hand, has maximum area when the grid circuit is resonated to the frequency of the driving signal. d-c milliammeters, therefore, are used as resonance indicators for the plate and grid circuits.

11.21 (a) From Eq (11.17) we see that the output of such a circuit would contain the d-c, the rectification, and the even harmonic terms.

(b) It could be used as a frequency doubler, quadrupler, etc.

11.22 Specifications: 20 W, 100 MHz, 50 Ω Load, $V_{cc} = 28$ V

Use Type MM 1558 transistor.

$$r_o = \frac{V_{cc}^2}{2P_{out}} = \frac{(28)^2}{2\times 20} = 19.6\ \Omega$$

$C_o = 54$ pf (Text page 863) ; $X_o = 29.4\ \Omega$

11.22 (concl.)

$$r_{os} = \frac{r_o X_o^2}{r_o^2 + X_o^2} = \frac{19.6(29.4)^2}{384+865} = 13.55\,\Omega$$

$$X_{os} = \frac{r_o^2 X_o}{r_o^2 + X_o^2} = \frac{(19.6)^2(29.4)}{384+865} = 9.05\,\Omega$$

Assume $Q_o = 15$, then

$$\omega_p L_2 = Q_o R_{eq} = 15 \times 13.55 = 203\,\Omega$$

$$L_2 = 0.323\ \mu h$$

$$X_m = 203 - 9.05 = 194\,\Omega$$

$$a = \sqrt{\frac{R_m}{R_L}} = \sqrt{\frac{13.55}{50}} = \sqrt{0.271} = 0.52$$

$$X_3 \doteq \frac{X_m}{1-a} = \frac{194}{1-0.52} = 403\,\Omega$$

$$X_4 = kX_3 = 0.925 \times 403 = 372\,\Omega$$

$$C_4 = \frac{1}{2\pi(100\times10^6)(372)} = 4.27\ pf$$

$$C_3 = \frac{1}{2\pi(100\times10^6)(403)} = 3.95\ pf$$

CHAPTER 12

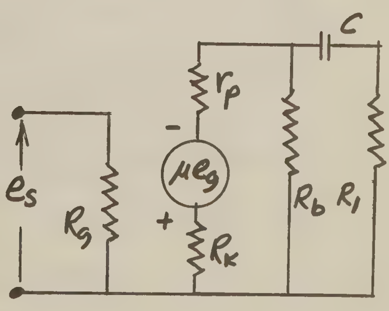
12.1

$$i_p = \frac{\mu e_g}{r_p + R + R_K}$$

$$i_p = \frac{\mu e_s}{r_p + R + (\mu+1)R_K}$$

where

$$R = R_b \| R_1$$



12.1 (concl.)

$$A_{vf} = \frac{-\mu R}{r_p + R + (\mu+1)R_K}$$

Gain with no feedback is

$$A_v = \frac{-\mu R}{r_p + R}$$

$$A_{vf} = \frac{\dfrac{-\mu R}{r_p+R}}{1 + \dfrac{(\mu+1)R_K}{r_p+R}} = \frac{A_v}{1 + \left(\dfrac{\mu R}{r_p+R}\right)\left(\dfrac{\mu+1}{\mu R}\right)R_K}$$

$$A_{vf} = \frac{A_v}{1 + f_v A_v} \quad \text{where } f_v = \frac{-(\mu+1)R_K}{\mu R}$$

$$A_v = \frac{-(80)(16.7)}{60 + 16.7} = -17.4$$

$$f_v = \frac{-(80+1)(500)}{80\,(16700)} = -0.303$$

$$A_{vf} = \frac{-17.4}{1 + (17.4)(0.0303)} = \frac{-17.4}{1+0.527} = -11.4$$

if μ decreases 10%, A_v decreases 10%

$$A_v = 0.90 \times 17.4 = -15.65$$

$$A_{vf} = \frac{-15.65}{1 + (15.65)(0.0303)} = \frac{-15.65}{1 + 0.475} = -10.60$$

$$\%\ \text{decrease} = \frac{11.4 - 10.6}{11.4} = 7\,\%$$

12.2 Using Eq (12.4), we obtain

$$0.10\% = \frac{10\%}{1+f_v A_v}$$

$$f_v A_v = \frac{10-0.10}{0.10} = 99$$

$$1000 = \frac{A_v}{1+99} \quad \text{and} \quad A_v = 100{,}000$$

$$f_v = \frac{99}{10^5} = 99\times10^{-5}$$

Correction: Answers given in Text on page 874 are incorrect.

12.3 (a)

$$\omega_{2f} = 2\,\omega_2 = 2\times10\times10^6 = 20\times10^6 \text{ r/s}$$

$$\omega_{2f} = 2\omega_2 = (1+f_v A_v)\omega_2$$

$$f_2 A_v = 2-1 = 1 \;\;\&\;\; f_v = \frac{-1}{50} = -0.02$$

(b)

$$A_v(j\omega_2) = \frac{A_{vr}}{1+j\,\omega_2/\omega_2} = 0.707\,A_{vr}\,\angle{-45^\circ}$$

$$f_v A_v(j\omega_2) = 0.02\times0.707\times50\,\angle{-45^\circ} = 0.707\,\angle{-45^\circ}$$

$$A_{vrf}(j\omega_2) = \frac{0.707\,A_{vr}\,\angle{-45^\circ}}{1+0.707\,\angle{-45^\circ}} = \frac{0.707\,A_{vr}\,\angle{-45^\circ}}{1.5-j0.5}$$

$$= \frac{0.707\,A_{vr}\,\angle{-45^\circ}}{1.58\,\angle{-18.4^\circ}} = \frac{-0.707\times50}{1.58}\,\angle{-26.6^\circ}$$

$$= -22.3\,\angle{-26.6^\circ} \;\;\&\;\; A_{vrf} = \frac{-50}{2} = -25$$

$$\text{Decrease in gain} = \frac{25-22.3}{25} = 10.8\%$$

12.3 (concl.)

Yes. The phase angle is $-26.6°$ with feedback at $\omega_2 = 10 \times 10^6$ r/s. Without feedback it is $-45°$

12.4 (a) Use negative feedback.

$$2\% = \frac{10\%}{1 + f_v A_v}$$

$$f_v A_v = \frac{10-2}{2} = 4$$

(b) Driving signal has to be increased by the factor $1 + f_v A_v = 1 + 4 = 5$, i.e.,

$$v_{sf} = 5 \times 10 \sin \omega t = 50 \sin \omega t \text{ volts}$$

12.5 $A_{vr} = -20$ and $\omega_2 = 40 \times 10^6$ r/s

(a)

$$A_{vH(3)}(j\omega_2) = \frac{(-20)^3 \angle -135°}{[1+1]^{3/2}} = -2830 \angle -135°$$

(b) $3\theta_H = 180°$; $\theta_H = 60° = \tan^{-1}\frac{\omega_x}{\omega_2} = \tan^{-1}\sqrt{3}$

$$\omega_x = \sqrt{3}\,\omega_2 = \sqrt{3} \times 40 \times 10^6 = 69.3 \times 10^6 \text{ r/s}$$

$$A_{vH(3)}(j\omega_x) = \frac{-8000 \angle -180°}{[1 + (\sqrt{3})^2]^{3/2}} = \frac{-8000}{8} \angle -180°$$

$$= -1000 \angle -180°$$

(c) $1000 f_v < 1.0$ so $f_v(\max) = \frac{1}{1000} = 0.001$

12.6 Correction: change Fig 12.5 to Fig 12.6.

$$A_{vr} = -100, \quad f_v = -0.0001, \quad \omega_2 = 5\times10^6 \text{ r/s}, \quad \omega_1 = 100 \text{ r/s}.$$

$$A_{v(3)}(j\omega_2) = \frac{(-100)^3 \angle -135^\circ}{[1+1]^{3/2}} = -35.3\times10^4 \angle -135^\circ$$

$$A_{vf(3)}(j\omega_2) = \frac{-35.3\times10^4 \angle -135^\circ}{1+35.3 \angle -135^\circ} = \frac{-35.3\times10^4 \angle -135^\circ}{1-25-j25}$$

$$= \frac{-35.3\times10^4 \angle -135^\circ}{34.8 \angle -133.8^\circ} = 1.015\times10^4 \angle -1.2^\circ$$

$$A_{v(3)}(j2\omega_1) = \frac{(-100)^3}{\left[1-j\frac{\omega_1}{2\omega_1}\right]^{3/2}} = \frac{-1\times10^6 \angle 79.5^\circ}{1.397} = -71.5\times10^4 \angle 79.5^\circ$$

$$A_{vf(3)}(j2\omega_1) = \frac{-71.5\times10^4 \angle 79.5^\circ}{1+71.5 \angle 79.5^\circ} = \frac{-71.5\times10^4 \angle 79.5^\circ}{1+13+j70}$$

$$= \frac{-71.5\times10^4 \angle 79.5^\circ}{71.4 \angle 78.7^\circ} = -1\times10^4 \angle 0.80^\circ$$

The gains at $\omega_2 = 5\times10^6$ r/s and $\omega = 200$ r/s are essentially equal to $A_{vrf(3)} = -1\times10^4 \angle 0^\circ$.

12.7

$$A_v = \frac{-R_L h_{fe}}{(h_{ie}+R_s)} = \frac{-40R_L}{(1500+500)}$$

$$1\% = \frac{10\%}{1+f_v A_v} \quad \text{so } f_v A_v = 10-1 = 9$$

$$A_v = (1+f_v A_v) A_{vf} = 10(-10) = -100$$

$$f_v = \frac{-9}{100} = -0.09$$

12.7 (concl.)

$$R_L = \frac{-(h_{ie}+R_s)A_v}{h_{fe}} = -\frac{(2000)(-100)}{40} = 5000\,\Omega$$

$$R_e = \frac{-f_v R_L h_{fe}}{1+h_{fe}} = \frac{0.09\times 5000\times 40}{1+40} = 439\,\Omega$$

12.8 The values listed on page 666 are compute with the following expressions:

$$A_i = \frac{-y_{fe}Y_L}{y_{ie}y_{oe}-y_{re}y_{fe}+y_{ie}Y_L}$$

$$Y_{in} = y_{ie} - \frac{y_{re}y_{fe}}{y_{oe}+Y_L}$$

$$Y_o = y_{oe} - \frac{y_{re}y_{fe}}{y_{ie}+Y_s}$$

12.9 Using the defining relations given in Eq (12.40 we derive the expressions for the model in Fig 12.10(b) as follows:

with the output shorted, i.e., $v_2 = 0$:

$$i_s = G_f v_1 + i_1 = G_f v_1 + \frac{v_1}{h_i} = \frac{(h_i+R_f)v_1}{R_f h_i}$$

$$h_{Mi} = \frac{v_1}{i_s} = \frac{h_i R_f}{h_i+R_f}$$

$$i_o = i_f + h_f i_1 \; ; \; i_1 = \frac{R_f i_s}{h_i+R_f} \; ; \; i_f = \frac{-h_i i_s}{h_i+R_f}$$

$$i_o = \left[\frac{h_f R_f - h_i}{h_i+R_f}\right] i_s \quad \text{and} \quad h_{Mf} = \frac{i_o}{i_s} = \left[\frac{h_f R_f - h_i}{h_i+R_f}\right]$$

12.9 (concl.)

With the input open, i.e., $i_s = 0$:

$$v_1 = h_i i_1 + h_r v_2, \text{ and } i_1 = \frac{v_2 - h_r v_2}{h_i + R_f}$$

$$h_{Mr} = \frac{v_1}{v_2} = h_r + \frac{(1-h_r)h_i}{h_i + R_f}$$

$$i_o = h_o v_2 + h_f i_1 + i_f = h_o v_2 + (h_f + 1) i_1 \quad \left(\begin{matrix}\text{since}\\ i_f = i_1\end{matrix}\right)$$

$$i_o = h_o v_2 + \frac{(h_f+1)(1-h_r)v_2}{h_i + R_f}$$

$$h_{Mo} = \frac{i_o}{v_2} = h_o + \frac{(h_f+1)(1-h_r)}{h_i + R_f}$$

12.10 The input loop equation is

$$v_1 = h_i i_1 + h_r (v_2 - v_f) + v_f \quad \text{where } v_f = R_f (i_1 + i_2)$$

$$= [h_i + (1-h_r)R_f] i_1 + h_r v_2 + (1-h_r) R_f i_2 \quad (1)$$

The output nodal equation is

$$i_2 = h_f i_1 + h_o (v_2 - v_f) = h_f i_1 + h_o v_2 - h_o R_f (i_1 + i_2)$$

$$i_2 = \frac{(h_f - h_o R_f) i_1 + h_o v_2}{1 + h_o R_f} \quad (2)$$

For $v_2 = 0$:

$$h_{Mf} = \frac{i_2}{i_1} = \frac{h_f - h_o R_f}{1 + h_o R_f}$$

For $i_1 = 0$:

$$h_{Mo} = \frac{i_2}{v_2} = \frac{h_o}{1 + h_o R_f}$$

12.10 (concl.)

Substituting Eq (2) into Eq (1) for i_2, we ge

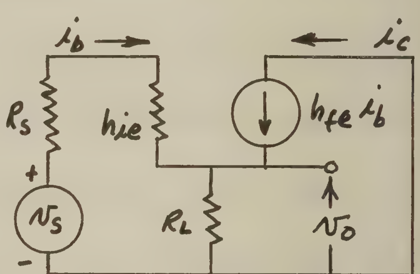
$$v_1 = \left[h_i + \frac{(1-h_r)(1+h_f)R_f}{1+h_o R_f} \right] i_1 + \left[\frac{h_r + h_o R_f}{1 + h_o R_f} \right] v_2$$

For $v_2 = 0$: For $i_1 = 0$

$$h_{Mi} = \frac{v_1}{i_1} = h_i + \frac{(1-h_r)(1+h_f)}{h_o + G_f}; \qquad h_{mr} = \frac{h_r + h_o R_f}{1 + h_o R_f}$$

12.11 The solution of this problem consists of substituting the numerical values of the modified h-parameters given on page 669 into the standard h-parameter expressions given in TABLE 5.3, page 237.

12.12



Without feedback,

$$A_v = \frac{h_{fe} R_L}{R_s + h_{ie}}$$

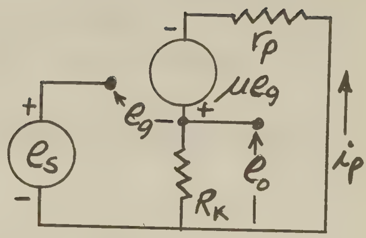
With feedback, $v_s = (h_{ie} + R_s + R_L) i_b + R_L h_{fe} i_b$

$$v_o = R_L (1+h_{fe}) i_b = \frac{(1+h_{fe}) R_L v_s}{h_{ie} + R_s + (1+h_{fe}) R_L}$$

$$A_{vf} = \frac{v_o}{v_s} = \frac{(1+h_{fe})R_L}{h_{ie}+R_s} \cdot \frac{1}{1 + \frac{(1+h_{fe})R_L}{h_{ie}+R_s}} \doteq \frac{A_v}{1+A_v} = \frac{A_v}{1+f_v A_v}$$

$f_v = 1$

12.13 Without feedback,



$$A_v = \frac{\mu R_K}{r_p + R_K}$$

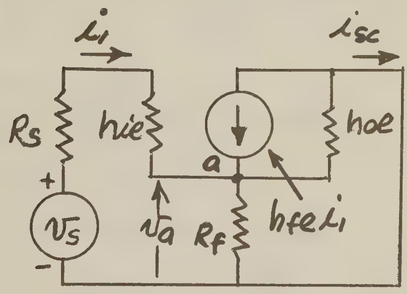
With feedback, $i_p = \dfrac{\mu e_g}{r_p + R_K} = \dfrac{\mu(e_s - R_K i_p)}{r_p + R_K}$

$$e_o = R_K i_p = \frac{R_K \mu e_s}{r_p + (\mu+1) R_K}$$

$$A_{vf} = \frac{e_o}{e_s} = \frac{\mu R_K}{r_p + R_K} \cdot \frac{1}{1 + \frac{\mu R_K}{r_p + R_K}} = \frac{A_v}{1 + A_v} = \frac{A_v}{1 + f_v A_v}$$

$f_v = 1$

12.14 At node a:



$$i_1 - \frac{v_a}{R_f} + h_{fe} i_1 - h_{oe} v_a = 0$$

$$v_a = \frac{R_f (1 + h_{fe}) i_1}{1 + h_{oe} R_f}$$

$$i_{sc} = h_{oe} v_a - h_{fe} i_1 = \frac{(h_{oe} R_f - h_{fe}) i_1}{1 + h_{oe} R_f}$$

$$v_s = (R_s + h_{ie}) i_1 + v_a = (R_s + h_{ie}) i_1 + \frac{R_f (1 + h_{fe}) i_1}{1 + h_{oe} R_f}$$

$$i_{sc} = \frac{(h_{oe} R_f - h_{fe}) v_s}{(R_s + h_{ie})(1 + h_{oe} R_f) + (1 + h_{fe}) R_f}$$

12.14 (Concl.)

Removing the short circuit, we can determine v_{oc}.

$$v_{oc} = R_f i_1 - r_{oe} h_{fe} i_1 = \frac{(R_f - r_{oe} h_{fe}) v_s}{R_s + h_{ie} + R_f}$$

$$Z_o = \frac{v_{oc}}{i_{sc}} = \frac{(R_f - r_{oe} h_{fe})(R_s + h_{ie})(1 + h_{oe} R_f) + (1 + h_{fe})}{(R_s + h_{ie} + R_f)(h_{oe} R_f - h_{fe})}$$

$$Z_o \doteq r_{oe} + \frac{h_{fe} r_{oe} R_f}{R_s + h_{ie} + R_f} \qquad \left\{ \begin{array}{l} h_{fe} r_{oe} \gg R_f \\ h_{oe} R_f \ll 1 \end{array} \right\}$$

12.15

$$V_{o1} = -h_{fe1} I_{b1} R_{o1} \| h_{ie2}$$

$$V_1 = [h_{ie1} + (1 + h_{fe1}) R_e] I_{b1}$$

$$A_{v1} = \frac{V_{o1}}{V_1} = \frac{-h_{fe1} R_{o1} \| h_{ie2}}{h_{ie1} + (1 + h_{fe1}) R_e}$$

$$V_{o2} = -h_{fe2} I_{b2} R_{o2} \| R_f = -h_{fe2} R_{o2} \| R_f \frac{V_{o1}}{h_{ie2}}$$

$$A_{v2} = \frac{V_{o2}}{V_{o1}} = \frac{-h_{fe2} R_{o2} \| R_f}{h_{ie2}}$$

12.16 Let us start at the output end of the circuit in Fig P12.16 and work towards the input end. With R_f connected to ground,

$$I_{o2} = \frac{R_{c2} I_{c2}}{R_{c2} + R_{o2}} = k_2 I_{c2} = k_2 h_{fe2} I_{b2}$$

where $k_2 = \dfrac{R_{c2}}{R_{c2} + R_{o2}}$

12.16 (cont.)

$$I_{b2} = \frac{-R_{o1} I_{c1}}{R_{o1}+R_{in2}} = -k_1 I_{c1} = -k_1 h_{fe1} I_{b1}$$

where $R_{o1} = R_{c1} \| R_{B2}$, $R_{in2} = h_{ie2} + R_e(1+h_{fe2})$

$$k_1 = \frac{R_{o1}}{R_{o1}+R_{in2}}$$

$$I_{b1} = \frac{R_{B1} I_s}{R_{B1}+h_{ie1}} = k_s I_s \quad \text{and} \quad k_s = \frac{R_{B1}}{R_{B1}+h_{ie1}}$$

$$A_{i1} = \frac{I_{b2}}{I_s} = -k_s k_1 h_{fe1} \quad \text{and} \quad A_{i2} = \frac{I_{o2}}{I_{b2}} = k_2 h_{fe2}$$

$$A_{i(2)} = \frac{I_{o2}}{I_s} = A_{i1} A_{i2}$$

$$I_f \doteq \frac{-R_e I_{e2}}{R_e+R_f} \quad \text{(with } R_f \text{ connected to ground)}$$

$$I_f = f_i I_{e2} \quad \text{and} \quad f_i \doteq \frac{-R_e}{R_e+R_f}$$

with R_f connected to the base of T_1,

$$A_{if(2)} = \frac{A_{i(2)}}{1+f_i A_{i(2)}} \quad \text{and} \quad A_{vf(2)} = \frac{R_{o2} A_{if(2)}}{R_s+R_{in1}}$$

For the numerical values given in Fig P12.16,

$k_1 = 0.361$, $\quad k_2 = 0.80$, $\quad k_s = 0.91$

$A_{i1} = -0.91 \times 0.361 \times 80 = -0.328 \times 80 = -26.3$

$A_{i2} = 0.80 \times 80 = 64$

12.16 (concl.)

$$A_{i(2)} = -263 \times 64 = -1680$$

$$f_i \doteq \frac{-100}{100+20{,}000} \doteq -0.005$$

$$A_{if(2)} = \frac{-1680}{1+(0.005)(1680)} = \frac{-1680}{1+8.40} = -179$$

$$A_{vf(2)} = \frac{R_{o2}(-179)}{R_s + R_{in1}}$$

$$R_{in1} = \frac{h_{ie1}}{1+f_i A_{i(2)}} = \frac{2000}{1+8.40} = 213\,\Omega$$

$$A_{vf(2)} = \frac{2000(-179)}{1000+213} = -295$$

12.17 The nodal equation at the input node of Fig 12.15(b) is

$$\frac{V_s(s) - V_i(s)}{R_s} + [V_o(s) - V_i(s)]\, s\, C_f = 0 \qquad \text{(see Eq(12.54))}$$

$$V_o(s)\left[\frac{1}{A_v R_s} + \frac{s C_f}{A_v} - s C_f\right] = \frac{V_s(s)}{R_s}$$

$$V_o(s) = \frac{V_s(s)}{R_s\left[\frac{1}{A_v R_s} + \frac{(1-A_v) s C_f}{A_v}\right]} \doteq \frac{A_v V_s(s)}{(1-A_v) R_s C_f s}$$

$$V_o(s) \doteq \frac{-V_s(s)}{R_s C_f s}$$ The s in the denominator indicates integration.

$$v_o(t) \doteq \frac{-1}{R_s C_f} \int v_s \, dt$$

12.18 We can obtain an easy solution by using the result in Eq (12.57).

$$V_o(s) = -\frac{R_f}{Z_s(s)} V_s(s) = -\frac{R_f}{\frac{1}{sC_s}} V_s(s)$$

$$V_o(s) = -R_f C_s \, s \, V_s(s)$$

Multiplying by s indicates differentiation.

$$v_o(t) = -R_f C_s \frac{dv_s}{dt}$$

12.19 Referring to Fig P12.19, we can write

$$I_s = I_1 - I_f = \frac{V_i}{R_{in}} + \frac{(V_i - V_o)}{R_f} = \frac{V_o}{A_v R_{in}} + \frac{V_o}{A_v R_f} - \frac{V_o}{R_f}$$

$$V_s = R_s I_s + V_i = R_s I_s + \frac{V_o}{A_v}$$

$$= R_s V_o \left[\frac{1}{A_v R_{in}} + \frac{1}{A_v R_f} - \frac{1}{R_f} + \frac{1}{A_v R_s}\right]$$

Correction: change R_s to R_o, i.e., $I_o = \frac{R_f I_s}{R_o}$

$$= -\frac{R_s V_o}{R_f}\left[1 - \frac{1}{A_v}\left(\frac{R_f}{R_{in}} + 1 + \frac{R_f}{R_s}\right)\right] \doteq \frac{-R_s V_o}{R_f}$$

$V_o \doteq -\frac{R_f V_s}{R_s}$ and $A_v = -\frac{R_f}{R_s}$ where $\frac{1}{A_v}\left(\frac{R_f}{R_{in}} + 1 + \frac{R_f}{R_s}\right) \ll 1$

Also,

$$I_s = V_o\left[\frac{1}{A_v R_{in}} + \frac{1}{A_v R_f} - \frac{1}{R_f}\right] \doteq \frac{-V_o}{R_f} = \frac{R_o I_o}{R_f}$$

$I_o \doteq \frac{R_f I_s}{R_o}$ and $A_{if} = \frac{I_o}{I_s} \doteq \frac{R_f}{R_o}$

12.19 (concl.) From the exact expression,

$$I_o = -\frac{I_s}{R_o}\frac{1}{\left[\frac{1}{A_v R_{in}} + \frac{1}{A_v R_f} - \frac{1}{R_f}\right]} = \frac{R_f I_s}{R_o}\left[\frac{1}{1 - \frac{R_f}{A_v R_{in}} - \frac{1}{A_v}}\right]$$

$$\frac{I_o}{I_s} = \frac{R_f}{R_o}\left[\frac{1}{1 - \frac{(R_f + R_{in})}{A_v R_{in}}}\right]$$

Now let us get A_v in terms of $A_i = \frac{I_o}{I_i}$.

$$A_v = \frac{V_o}{V_i} = -\frac{R_o I_o}{V_i} = \frac{-R_o I_o}{R_{in} I_i} = -\frac{R_o}{R_{in}} A_i$$

$$A_{if} = \frac{I_o}{I_s} = \frac{R_f}{R_o}\left[\frac{1}{1 + \frac{R_f + R_{in}}{R_o A_i}}\right] = \frac{R_f}{R_o}\left[\frac{A_i}{A_i + \frac{(R_f + R_{in})}{R_o}}\right]$$

$$\doteq \frac{R_f}{R_o}\left[\frac{A_i}{\frac{R_f}{R_o} + A_i}\right] = \frac{A_i}{1 + \frac{R_o}{R_f} A_i} = \frac{A_i}{1 + f_i A_i}$$

where $R_f \gg R_{in}$

$$f_i \doteq \frac{R_o}{R_f}$$

For $f_i A_i \gg 1$, $A_{if} = \frac{I_o}{I_s} = \frac{R_f}{R_o}$

This check the approximate expression for A_{if} on the bottom of page 169.

12.20 (a) & (b) From Fig P12.20, we can write the following nodal equations:

$$I_s + I_f - I_i = \frac{(V_s - V_i)}{R_s} + \frac{(V_o - V_i)}{R_f} - \frac{V_i}{R_{in}} = 0 \qquad (1)$$

$$I_o - I_L - I_f = \frac{(A_v V_i - V_o)}{R_{out}} - \frac{V_o}{R_L} - \frac{(V_o - V_i)}{R_f} = 0 \qquad (2)$$

$$\frac{V_s}{R_s} + \frac{V_o}{R_f} - \left(\frac{1}{R_s} + \frac{1}{R_f} + \frac{1}{R_{in}}\right) V_i = \frac{V_s}{R_s} + \frac{V_o}{R_f} - G_1 V_i = 0 \qquad (1a)$$

$$\left(\frac{A_v}{R_{out}} + \frac{1}{R_f}\right) V_i - \left(\frac{1}{R_{out}} + \frac{1}{R_L} + \frac{1}{R_f}\right) V_o = G_3 V_i - G_2 V_o = 0 \qquad (2a)$$

where $G_1 = \frac{1}{R_s} + \frac{1}{R_f} + \frac{1}{R_{in}}$

$G_2 = \frac{1}{R_{out}} + \frac{1}{R_L} + \frac{1}{R_f}$ and $G_3 = \frac{A_v}{R_{out}} + \frac{1}{R_f}$

From (2a), $V_i = \frac{G_2 V_o}{G_3}$. Substitute in (1a)

$$V_o = \frac{V_s}{R_s}\left[\frac{1}{\frac{G_1 G_2}{G_3} - \frac{1}{R_f}}\right] = -\frac{R_f V_s}{R_s}\left[\frac{1}{1 - \Delta}\right]$$

$$V_o \doteq -\frac{R_f V_s}{R_s}(1 + \Delta) \quad \text{where } \Delta = \frac{G_1 G_2 R_f}{G_3}$$

(c) $G_1 = 2.3 \times 10^{-4}\ \mho$; $G_2 = 102.2 \times 10^{-4}\ \mho$; $G_3 = -100\ \mho$

$\Delta = -0.001175$

$A_v = -\frac{5 \times 10^4}{5 \times 10^3}\left[1 - 0.001175\right] = -10\left[0.998825\right] = -9.98825$

CHAPTER 13

13.1

$$\frac{f_{max}}{f_{min}} = \frac{C_{max}}{C_{min}} = \frac{1070}{80} = 13.4$$

Divide frequency range into 3 bands:

20 - 200 ; 200 - 2000 ; 2000 - 20,000 Hz

$$f_{(max)} = \frac{1}{2\pi R_1 C_{min}} = \frac{1}{2\pi R_1 \times 80 \times 10^{-12}} = \frac{1.985 \times 10^9}{R_1}$$

For $f_{(max)} = 200$ Hz ; $R_1 = 9.93 \times 10^6\ \Omega$

Since we have 35% excess frequency range, let us increase $f_{(max)}$ by 15%.

Make $R_1 \doteq 0.85 \times 9.93 = 8.45\ M\Omega \doteq 8.5\ M\Omega$

$$f_{(min)} = \frac{1}{2\pi \times 8.5 \times 10^6 \times 1070 \times 10^{-12}} = 17.50\ Hz$$

The final design is tabulated below:

$R_1 = R_2$	Frequency Range	
8.50 MΩ	17.5 to 234	Hz
0.85 "	175 to 2340	"
85 kΩ	1750 to 23,400	"

13.2

$$g_m R_o \geq 29 + \frac{23 R_o}{R} + \frac{4 R_o^2}{R^2} = 29 + 23k + 4k^2$$

If optimize $(g_m R_o)$ by setting $\frac{d(g_m R_o)}{dk} = 0$, we get $k = \frac{R_o}{R} = -\frac{23}{8}$. This is not a practical

13.2 (Concl.)

result because either R_o or R must be negative. From the expression for $g_m R_o$, we see that $g_m R_o$ attains a minimum value of 29 when R is so much larger than $23R_o$ that the last two terms of this expression reduce to zero, i.e.,

$$g_m R_o \geq 29 + 0 + 0 \qquad (\text{where } R \gg 23 R_o)$$

If $R = R_o$, then

$$g_m R_o \geq 29 + 23 + 4 = 56$$

The value of $R_o = r_p \| R_b$ depends upon the Q-point and the plate supply voltage E_{bb}.

<u>13.3</u> If $R_o = r_p \| R_b \doteq r_p$, i.e., $R_b \gg r_p$, then

$$g_m R_o \doteq g_m r_p = \mu \geq 29 + \frac{23 R_o}{R} + \frac{4 R_o^2}{R^2}$$

$\therefore \mu\,(\text{minimum}) = 29$

Let us try the 12AX7 triode (see page 870) since it has a $\mu \doteq 100$.

<u>12AX7</u>: $\mu = 95$, $r_p = 60\,K\Omega$, $I_b = 0.50$ ma, $E_c = -1.5$ v, $E_b = 150$ v, $R_b = 200\,K\Omega$

$$g_m = \frac{\mu}{r_p} = \frac{95}{60 \times 10^3} = 1585\,\mu\mho$$

$$R_o = r_p \| R_b = 60 \| 200 = 46.1\,K\Omega$$

$$g_m R_o = 1585 \times 10^{-6} \times 46.1 \times 10^3 = 73.2$$

13.3 (concl.)

This is sufficient gain for the case where $R = R_o$, i.e.,

$$g_m R_o \geq 29 + 23 + 4 = 56$$

From Eq (13.10),

$$f_o = \frac{1}{2\pi RC} \cdot \frac{1}{\sqrt{6 + 4R_o/R}}$$

$$RC = \frac{1}{2\pi f_o \sqrt{6+4}} = \frac{1}{2\pi \times 2000 \sqrt{10}}$$

$$= \frac{79.5 \times 10^{-6}}{\sqrt{10}}$$

$$C = \frac{79.5 \times 10^{-6}}{46.1 \times 10^{3} \sqrt{10}} = \frac{0.00172\ \mu f}{\sqrt{10}}$$

$$C = \frac{0.00172}{3.16} = 0.000545\ \mu f$$

$$R = 46.1 \times 10^{3}\ \Omega$$

13.4

$$h_{fe} \geq 23 + \frac{29R}{R_o} + \frac{4R_o}{R} = 23 + 29k + 4k^{-1}$$

$$\frac{dh_{fe}}{dk} = 0 + 29 - \frac{4}{k^2} = 0 \quad \text{and} \quad k = \sqrt{\frac{4}{29}} = 0.373$$

$$h_{fe} = 23 + 29(0.373) + \frac{4}{0.373} = 23 + 10.8 + 10.7$$

$$h_{fe} = 44.5 \quad \text{and} \quad k = \frac{R}{R_o} = 0.373$$

$\underline{13.5}$ $h_{fe} \geq 23 + \dfrac{29R}{R_o} + \dfrac{4R_o}{R}$

For optimum $k = 0.373$, $h_{fe} = 44.5$

" $R = R_o$, i.e., $k = 1$, $h_{fe} = 23 + 29 + 4 = 56$

Let us use a Type 2N3251 (see page 846)

For $I_C = 1.0$ ma, $V_{CE} = 10$ V
$h_{fe} = 100$, $h_{ie} = 2000\ \Omega$, $h_{oe} = 10\ \mu\mho$

Let us assume $R = h_{ie} = 2000\ \Omega$

For optimum k: $R_o = \dfrac{2000}{0.373} = 5350\ \Omega$

$R_c \doteq R_o$ and $R_c I_c = 5.350 \times 1.0 = 5.350$ V

$V_{CC} \doteq R_c I_c + V_{CE} = 5.350 + 10 = 15.350$ V

If we make $R_o = R = 2000\ \Omega$, then

$V_{CC} \doteq 2 \times 1 + 10 = 12$ V

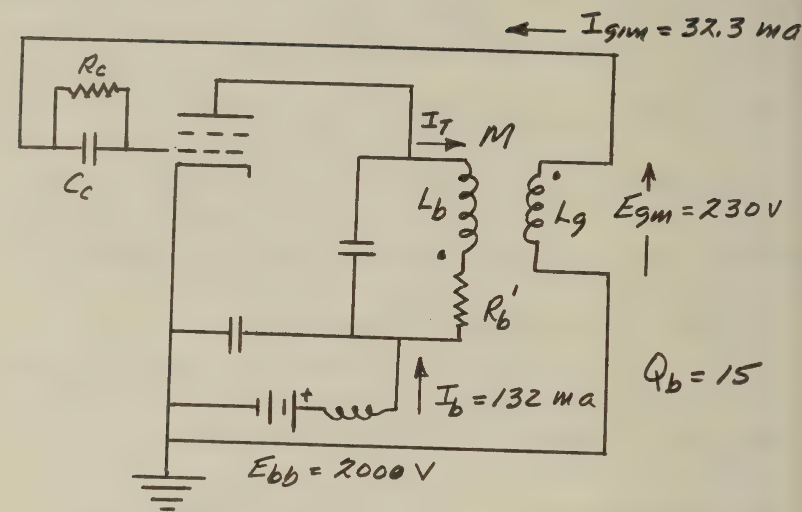
a saving of 3.5 V in V_{CC}. Using $R_o = R$, calculate the following value for C:

$$C = \frac{1}{2\pi f_o R\sqrt{6+4}} = \frac{1}{2\pi \times 1000 \times 2000\sqrt{10}}$$

$$= \frac{79.5 \times 10^{-9}}{\sqrt{10}} = 25.1 \times 10^{-9} = 0.0251\ \mu f$$

$R_c \doteq R_o = R = h_{ie} = 2000\ \Omega$

13.6

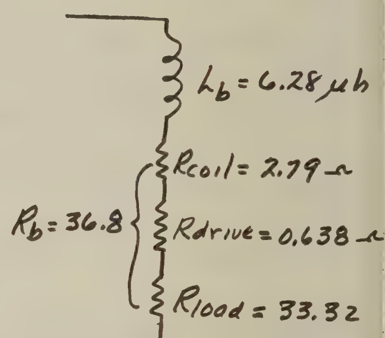


$$P_{drive} = \frac{E_{gm} I_{gim}}{2} = 3.70\text{ W}$$

$$R_C = \frac{E_{CC}}{I_C} = \frac{130}{0.0176} = 7390\ \Omega$$

$$I_{Tm} = \left[1 + (Q_b)^2\right]^{1/2} I_{pim}$$

$$= \left[1 + 225\right]^{1/2} (226) = 3410\text{ ma}$$



$$E_{gm} = j \omega M I_{Tm}$$

$$\omega M = \frac{230\text{ V}}{3.410\text{ a}} = 67.5\ \Omega \quad \text{and} \quad M = \frac{67.5}{2\pi \times 14} = 0.765\ \mu h$$

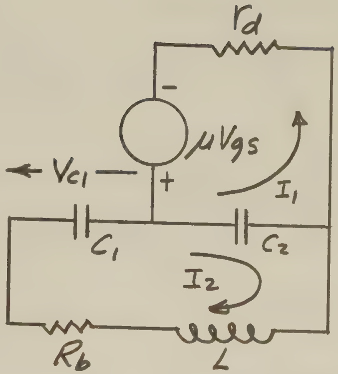
$$P_{coil} = \frac{I_{Tm}^2 R_{coil}}{2} = \frac{(3.410)^2 (2.79)}{2} = 16.25\text{ W}$$

$$P_{Total} = \frac{E_{pm} I_{pim}}{2} = \frac{1880 \times 0.226}{2} = 213\text{ W}$$

$$P_{load} = 213 - 16.25 - 3.70 = 193\text{ W}$$

13.7

$$\mu V_{gs} = Z_{11} I_1 + Z_{12} I_2 \quad (1)$$



$$0 = Z_{21} I_1 + Z_{22} I_2 \quad (2)$$

where

$$Z_{11} = r_d - jX_{c2}$$

$$Z_{12} = Z_{21} = -jX_{c2}$$

$$Z_{22} = R_b + j(X_L - X_{c1} - X_{c2}) = R_b + jX_2$$

Solving Eqs (1) and (2) for I_2,

$$I_2 = \frac{-\mu V_{gs} Z_{21}}{Z_{11} Z_{22} - Z_{12} Z_{21}} = \frac{-\mu V_{gs} Z_{21}}{\Delta}$$

$$\Delta = (r_d - jX_{c2})(R_b + jX_2) - (jX_{c2})^2$$

$$= r_d R_b + X_2 X_{c2} + X_{c2}^2 - j(R_b X_{c2} - r_d X_2)$$

Set j-term $=0$, to find condition for resonance.

$$R_b X_{c2} - r_d (X_L - X_{c1} - X_{c2}) = 0$$

$$r_d X_L = r_d \omega_0 L = r_d \left[\frac{1}{\omega_0 C_1} + \left(1 + \frac{R_b}{r_d}\right)\frac{1}{\omega_0 C_2}\right]$$

$$\omega_0^2 = \frac{1}{L}\left[\frac{1}{C_1} + \left(1 + \frac{R_b}{r_d}\right)\frac{1}{C_2}\right] \doteq \frac{C_1 + C_2}{C_1 C_2 L} \quad \left(\text{for } r_d \gg R_b\right)$$

Condition for oscillation: $V_{c1} \geq V_{gs}$

13.7 (concl.)

$$V_{C1} = X_{C1} I_2 = \frac{\mu V_{gs} X_{C1} X_{C2}}{r_d R_b + X_2 X_{C2} + X_{C2}^2} \geq V_{gs}$$

$$\frac{\mu X_{C2} X_{C1}}{r_d R_b + \underbrace{(X_L - X_{C1} - X_{C2})}_{0} X_{C2} + X_{C2}^2} = \frac{\mu X_{C1} X_{C2}}{r_d R_b + X_{C2}^2} \geq 1$$

$$\doteq \frac{\mu X_{C1} X_{C2}}{X_{C2}^2} \geq 1$$

$$\mu \geq \frac{X_{C2}}{X_{C1}} = \frac{C_1}{C_2}$$

(b) For stable operation, oscillators should no[t] be heavily loaded, i.e., $Q_b = \omega_0 L / R_b$ should be large. Q_b should be greater than 20. Under such conditions of operation we are justified in neglecting R_b.

13.8

The Hartley oscillator differs from the Colpitts oscillator in that the roles of the capacitances and inductances are interchanged. For $M = 0$, we have

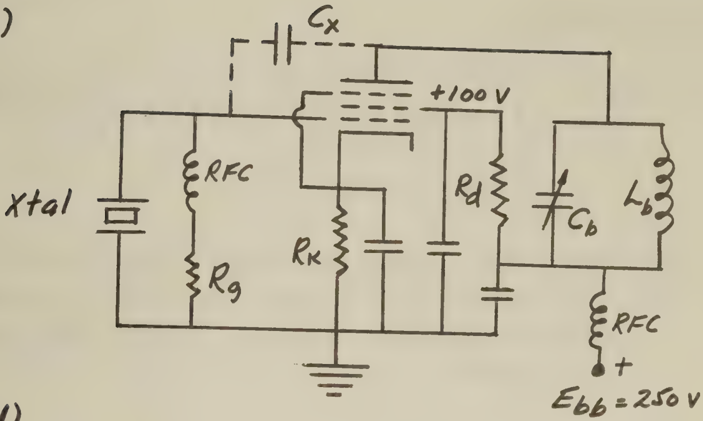
$$X_C + X_{L1} + X_{L2} = 0 \quad \text{and} \quad \frac{-1}{\omega_0 C} + \omega_0 (L_1 + L_2) = 0$$

$$\omega_0^2 = \frac{1}{(L_1 + L_2) C} \qquad \text{(Same as Eq (13.25))}$$

$$\frac{\mu X_{L1}}{X_{L2}} = \frac{\mu \omega_0 L_1}{\omega_0 L_2} = \frac{\mu L_1}{L_2} \geq 1$$

$$\mu \geq \frac{L_2}{L_1}$$

13.9 (a)



(b), (c), & (d)

Pentode has greater power sensitivity and for a given r-f output requires less r-f crystal current than the triode, resulting in lower crystal heating and better frequency stability. Pentode has a lower C_{gp} so there is less interaction or "pulling" on the xtal frequency by the plate tank circuit $L_b C_b$. If C_{gp} is too low, the drive can be increased by adding C_x; C_x, however, should be kept to an absolute minimum - 1 or 2 pf is usually sufficient.

(e) Excessive amplitude of oscillation causes overheating and can cause the xtal to fracture and destroy itself.

13.10

(a) & (b)

$$f_s = \frac{1}{2\pi\sqrt{L_x C_x}} = \frac{1}{2\pi\left[0.0253 \times 0.01 \times 10^{-12}\right]^{1/2}}$$

$$= 10 \times 10^6 \text{ Hz} = 10 \text{ MHz}$$

$$f_p = f_s\left[\frac{C_x + C_p}{C_p}\right]^{1/2} = 10\left[\frac{0.01 + 15 + 15}{15 + 15}\right]^{1/2}$$

13.10 (Concl.)

$$f_p = 10\left[1+0.000333\right]^{1/2} \doteq 10\left[1+\frac{0.000333}{2}\right]$$

$$\doteq 10.00166 \text{ MHz}$$

(c) Yes, the xtal oscillator circuit can be adjusted precisely to its operating frequency by such an external variable capacitor.

13.11

(a) The cathode follower circuit makes an ideal buffer stage. The 12AU7 triode circuit shown in Fig 6.25(b) on page 346 could be used. This circuit provides the following specifications:

$$R_{in} = 8.12\ M\Omega \ ; \quad R_{out} = 486\ \Omega$$

$$A_i = 374 \ ; \quad A_v = 0.923$$

$$G = A_i A_v = 345 \ ; \quad G_{db} = 25.4 \text{ db}$$

(b) The emitter follower circuit shown in Fig 5.41 (b) can be used as the buffer stage. For example, the Type 2N525 transistor (see page 238) in the common collector connection yields the following specifications:

$R_s = R_o = R_c = 2000\ \Omega$ (From Prob 13.5) ; $R_{load} = 500\ \Omega$

$A_i = 45$ (Fig 5.30) ; $A_v \doteq 1.0$ (Fig 5.31)

$G = A_i A_v = 45$ (Fig 5.32)

13.11 (Concl.)

$$R_i \doteq h_{ie} + (1+h_{fe})R_E = 1400 + (44+1)(500) = 23,900\ \Omega$$

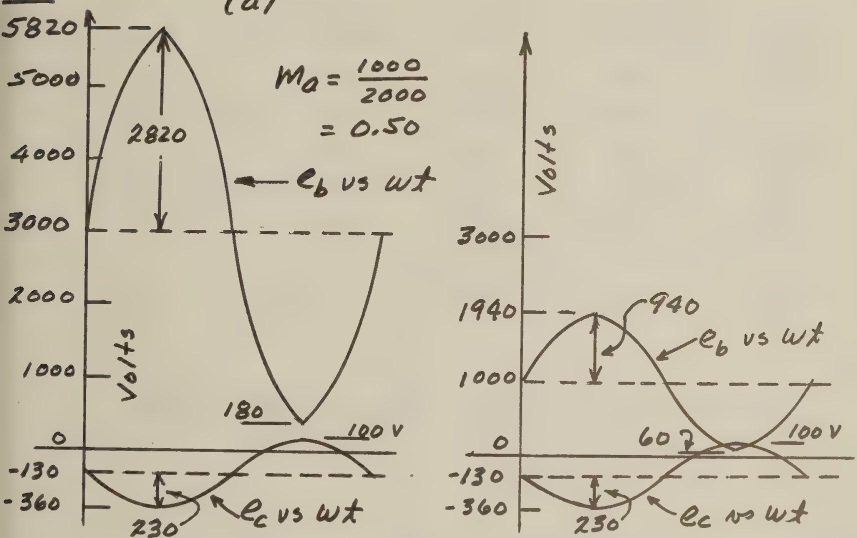
$$R_o \doteq \frac{h_{ie}+R_s}{1+h_{fe}} = \frac{1400+2000}{1+44} = 76\ \Omega$$

Another possibility is to use a transistor having a larger h_{fe} in the common emitter connection with emitter degeneration to provide a high input impedance.

CHAPTER 14

14.1

(a)



CREST VALUES of e_b and e_c

TROUGH VALUES of e_b and e_c

Crest conditions: All plate voltages and currents are multiplied by the factor $(1+M_a) = (1+0.5) = 1.50$

14.1 (concl.)

Trough Conditions: All plate voltages and current are multiplied by the factor $(1-m_a) = (1-0.50) = 0.50$

Grid voltages and currents remain the same as their carrier values. The waveforms of i_b and i_c have been omitted from the above sketches for the sake of simplicity and clarity. Complete waveforms are shown in Fig 11.16, page 620.

(b)

	Carrier	Crest	Trough
E_{pm}	1880	2820	940
I_{p1m}	227	340	114
I_b	132	198	66
$e_b(min)$	120	180	60
P_L	213	478	53.3
P_{bb}	264	594	66
P_p	51	116	12.7
η_p	80.8	80.8	80.8

(c)

$$P_{mod} = E_{bb} I_{bc} \frac{m_a^2}{2} = \frac{2000 \times 0.132\ (0.50)^2}{2}$$
$$= 33 \text{ watts}$$

14.2

$$R_m = \frac{E_{bb}}{I_b} = \frac{2000}{0.132} = 15{,}150\ \Omega$$

$$\frac{n_2}{n_1} = \sqrt{\frac{15{,}150}{8000}} = 1.35 \quad \text{(step-up ratio)}$$

14.3 (a)

$$f_c + f_1 = 1{,}000{,}000 + 100 = 1{,}000{,}100 \text{ Hz}$$
$$f_c - f_1 = 1{,}000{,}000 - 100 = 999{,}900 \text{ Hz}$$

$$f_c + f_2 = 1{,}000{,}000 + 1000 = 1{,}001{,}000 \text{ Hz}$$
$$f_c - f_2 = 1{,}000{,}000 - 1000 = 999{,}000 \text{ Hz}$$

$$f_c + f_3 = 1{,}000{,}000 + 5000 = 1{,}005{,}000 \text{ Hz}$$
$$f_c - f_3 = 1{,}000{,}000 - 5000 = 995{,}000 \text{ Hz}$$

$m_{a1} = 0.50$; $m_{a2} = 0.80$; $m_{a3} = 0.30$

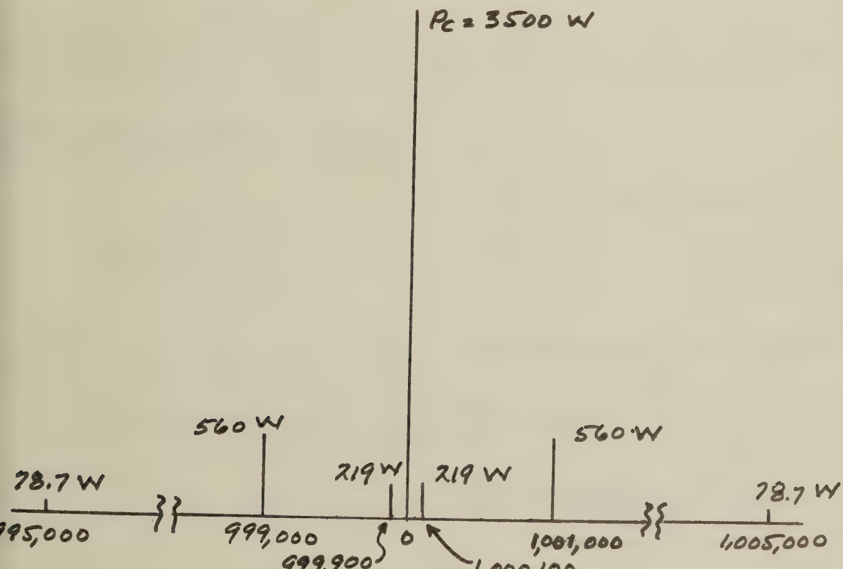
(b)

$$P_C = \frac{(10)^2(70)}{2} = 3500 \text{ W}$$

$$P_{USB1} = P_{LSB1} = 3500\left(\frac{0.50}{2}\right)^2 = 219 \text{ W}$$

$$P_{USB2} = P_{LSB2} = 3500\left(\frac{0.80}{2}\right)^2 = 560 \text{ W}$$

$$P_{USB3} = P_{LSB3} = 3500\left(\frac{0.30}{2}\right)^2 = 78.7 \text{ W}$$



14.4 $e = Zi = \dfrac{i}{Y}$

From Eq (10.11), $Y = \dfrac{1}{R}\left[1 + jQ\left(\dfrac{\omega}{\omega_0} - \dfrac{\omega_0}{\omega}\right)\right]$

(a) $Q = 10$

Carrier $f_c = 5$ MHz: $Y = \dfrac{1}{R}[1 + j0] = \dfrac{1}{R} + j0$

USB $(f_c + f_s) = 5.01$ MHz:

$$Y = \frac{1}{R}\left[1 + j10\left(\frac{5.01}{5} - \frac{5.0}{5.01}\right)\right] = \frac{1}{R}[1 + j\,0.04]$$

$$Y \doteq \frac{1}{R}\,\underline{\big|2.3^\circ}$$

LSB $(f_c - f_s) = 4.99$ MHz:

$$Y = \frac{1}{R}\left[1 + j10\left(\frac{4.99}{5} - \frac{5}{4.99}\right)\right] = \frac{1}{R}[1 - j0.04]$$

$$\doteq \frac{1}{R}\,\underline{\big|-2.3^\circ}$$

$$e(t) = E_{cm}\Big[\cos 2\pi(5\times10^6)t + 0.40\,\underline{\big|2.3^\circ}\cos 2\pi(4.99\times10^6)t$$

$$+ 0.40\,\underline{\big|-2.3^\circ}\cos 2\pi(5.01\times10^6)t\Big]$$

where $E_{cm} = R I_m$.

(b) $Q = 100$

USB $(f_c + f_s) = 5.01$ MHz:

$$Y = \frac{1}{R}\left[1 + j100\left(\frac{5.01}{5} - \frac{5}{5.01}\right)\right] = \frac{1}{R}[1 - j0.4]$$

$$\doteq \frac{1}{R}(1.076)\,\underline{\big|21.8^\circ}$$

14.4 (Concl.)

LSB $(f_c - f_s) = 4.99$ MHz:

$$Y = \frac{1}{R}(1.076)\angle -21.8^\circ$$

$$e(t) = E_{cm}\Big[\cos 2\pi(5\times10^6)t + 0.37\angle 21.8^\circ \cos 2\pi(4.99\times10^6)t$$
$$+ 0.37\angle -21.8^\circ \cos 2\pi(5.01\times10^6)t\Big]$$

These examples illustrate the effect of circuit Q upon the attenuation and the phase angles of the sidebands.

14.5 (a)

$$P_L = P_{Lc}\left(1 + \frac{m_a^2}{2}\right); \quad P_{Lc} = \frac{470}{1.5} = 313 \text{ W}$$

(b) $$E_{bb} I_{bc}\left[1 + \frac{m_a^2}{2}\right] = E_{bb} I_{bc}(1.5) = 470 + 100 = 570 \text{ W}$$

$$I_{bc} = \frac{570}{1.5\times 2000} = 190 \text{ ma}$$

$$P_{mod} = \frac{E_{bb} I_{bc} m_a^2}{2} = \frac{2000\times 0.190}{2} = 190 \text{ W}$$

(c) $$R_m = \frac{E_{bb}}{I_{bc}} = \frac{2000}{0.190} = 10{,}500\ \Omega$$

$$\frac{n_2}{n_1} = \sqrt{\frac{R_m}{R_{pp}}} = \sqrt{\frac{10{,}500}{7000}} = 1.226$$

14.6 From Eqs (14.28) and (14.29), we can write

$$i_{b1} + i_{b2} = 2I_{bo} + 2a_1 e_c + 2a_2 e_c^2 + 2a_2 e_s^2$$

$$= 2I_{bo} + 2a_1 E_{cm}\cos\omega_c t + 2a_2 E_{cm}^2 \cos^2\omega_c t$$
$$+ 2a_2 E_{sm}^2 \cos^2\omega_s t$$

14.6 (Concl.)

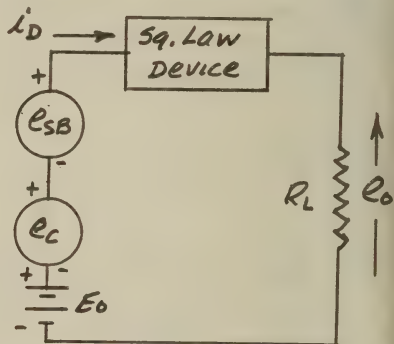
$$i_{b1} + i_{b2} = 2I_{bo} + 2a_1 E_{cm} \cos w_c t + a_2 E_{cm}^2 [1 - \cos 2w_c t] + a_2 E_{sm}^2 [1 - \cos 2w_s t]$$

The transformer does not pass d-c, so

$$e_{o2} = k_2 [2a_1 E_{cm} \cos w_c t - a_2 E_{cm}^2 \cos 2w_c t - a_2 E_{sm}^2 \cos 2w_s t]$$

14.7 (a) & (b)

we can use the circuit of Fig 14.7(a) by replacing e_s with the upper side band voltage



$$e_{SB} = E_{SB} \cos w_{SB} t$$

where $w_{SB} = w_c + w_s$.
Equations (14.23) and (14.24) apply if we substitute e_{SB} and w_{SB} respectively for e_s and w_s. The term of interest is the difference side frequency term of Eq (14.24), i.e.,

$$k E_{cm} E_{SB} \cos(w_{SB} - w_c) t = k E_{cm} E_{SB} \cos w_s t$$

(c) From the above equation, we see that if w_c is high by Δw_c, the recovered signal frequency w_s is low by Δw_c.

(d) The phase of $e_c = E_{cm} \cos w_c t$ does not appear in the frequency terms of Eq (14.24), so it does not affect the recovered signal e_s.

14.8

For modulator #2

$$i_{b3} = I_{bo} + a_1 e_{g3} + a_2 e_{g3}^2 ; \quad e_{g3} = E_{cm} \sin \omega_c t + E_{sm} \sin \omega_s t$$

$$i_{b4} = I_{bo} + a_1 e_{g4} + a_2 e_{g4}^2 ; \quad e_{g4} = E_{cm} \sin \omega_c t - E_{sm} \sin \omega_s t$$

$$i_{b3} - i_{b4} = 2a_1 E_{sm} \sin \omega_s t + 4a_2 E_{cm} E_{sm} \sin \omega_c t \sin \omega_s t$$

The output voltage e_{o2} of modulator is given by

$$e_{o2} = k(i_{b3} - i_{b4}) = 2k\Big[a_1 E_{sm} \sin \omega_s t + a_2 E_{cm} E_{sm} \cos(\omega_c - \omega_s)t - a_2 E_{cm} E_{sm} \cos(\omega_c + \omega_s)t\Big]$$

The output voltage of modulator #1 is given by Eq (14.30). Adding $e_{o1} + e_{o2}$, we get

$$e_{o1} + e_{o2} = 2k\Big[a_1 E_{sm} \cos \omega_s t + a_1 E_{sm} \sin \omega_s t + 2a_2 E_{cm} E_{sm} \cos(\omega_c - \omega_s)t\Big]$$

14.9 From Eqs (14.31) and (14.35),

$$e_o(t) = S(t)\, e_s(t) = 2E_{sm}\left[\frac{2}{\pi}\cos \omega_c t - \frac{2}{3\pi}\cos 3\omega_c t\right]\cos \omega_s t$$

$$= 2E_{sm}\left[\frac{2}{\pi}\cos \omega_c t \cos \omega_s t - \frac{2}{3\pi}\cos 3\omega_c t \cos \omega_s t\right]$$

$$= 2E_{sm}\left[\frac{1}{\pi}\cos(\omega_c - \omega_s)t + \frac{1}{\pi}\cos(\omega_c + \omega_s)t - \frac{1}{3\pi}\cos(3\omega_c - \omega_s)t - \frac{1}{3\pi}\cos(3\omega_c + \omega_s)t\right]$$

14.10

$$a = kT_r = \frac{k}{f_r} = 0.01 \times 10^{-5} = 0.10\,\mu s$$

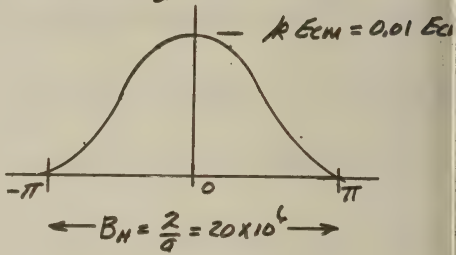
Freq separation = f_r = 100,000 Hz

14.10 (Concl.)

No. of lines from $-\pi$ to π $= 2n_\pi = \frac{2}{k} = \frac{2}{0.01} = 200$

$B_H = 2n_\pi f_r = 200 \times 10^5 = 20 \times 10^6$ Hz $= 20$ MHz

The envelope is given by Eq(14.41)



14.11

$a = kT_r = \frac{k}{f_r} = 0.01 \times 10^{-4} = 1 \times 10^{-6} = 1\ \mu s$

Freq separation $= f_r = 10^4 = 10{,}000$ Hz

No. lines from $-\pi$ to π $= 2n_\pi = \frac{2}{0.01} = 200$

$B_H = 2n_\pi f_r = 200 \times 10^4 = 2 \times 10^6 = 2$ MHz

B_H increases directly with the message speed.

14.12 (a)

$2^6 + 2^5 + 2^4 + 2^3 + 2^2 + 2^1 + 2^0 = 127$ discrete value

(b) Bit rate = (8 bits/channel)(24 channels)(8000)
$= 192$ bits $\times 8000 = 1{,}536{,}000$ bits/sec

(c) $B_H = \frac{1}{a} = \frac{1}{kT_r}$; $k = 0.50$

$f_r = 1.536 \times 10^6$; $a = kT_r = 0.50\,T_r$

$T_r = 0.652 \times 10^{-6}$ s ; $a = 0.50 \times 0.652 \times 10^{-6} = 0.326\ \mu s$

$B_H = \frac{1}{a} = \frac{10^6}{0.326} = 3.07$ MHz

14.13 From Eq (14.46),

$$\frac{1}{RC} \geqslant \frac{-m_a \omega_s \cos \omega_s t_1}{(1 + m_a \sin \omega_s t_1)}$$

$$\frac{d}{dt_1}\left[\frac{\cos \omega_s t_1}{(1+ m_a \sin \omega_s t_1)}\right] = \frac{-\omega_s \sin \omega_s t_1 (1+ m_a \sin \omega_s t_1)}{(1+ m_a \sin \omega_s t_1)^2}$$

$$- \frac{m_a \omega_s \cos^2 \omega_s t_1}{(1+ m_a \sin \omega_s t_1)^2} = 0$$

$$-\sin \omega_s t_1 - m_a (\sin^2 \omega_s t_1 + \cos^2 \omega_s t_1) = 0$$

$$-\sin \omega_s t_1 - m_a (1) = 0 ; \qquad RC \leq \frac{\sqrt{1 - m_a^2}}{m_a \omega_s}$$

$$\sin \omega_s t_1 = - m_a \quad \text{or} \quad \cos \omega_s t_1 = - \sqrt{1 - m_a^2}$$

Minus sign is needed in cosine expression because $90° \leq \omega_s t \leq 180°$. See Fig 14.13 (c).

4.14

Case of $f_o < f_c$: $f_o(\text{min}) = 550 - 455 = 95$ kHz

$f_o(\text{max}) = 1600 - 455 = 1145$ kHz

$$\frac{f_o(\text{max})}{f_o(\text{min})} = \frac{1145}{95} = 12.05$$

se of $f_o > f_c$: $f_o(\text{min}) = 550 + 455 = 1005$ kHz

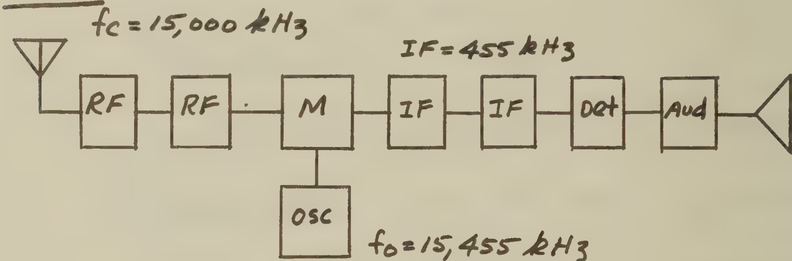
$f_o(\text{max}) = 1600 + 455 = 2055$ kHz

$$\frac{f_o(\text{max})}{f_o(\text{min})} = \frac{2055}{1005} = 2.05$$

14.14 (concl.)

It is much easier to construct an oscillator to tune over a 2-to-1 frequency range than over a 12-to-1 frequency range. Also it is much easier to make the 2-to-1 frequency range oscillator track over the broadcast band of 550-1600 kHz.

14.15



(b) $f_x = 15{,}020$ kHz

$IF_x = 15{,}455 - 15{,}020 = 435$ kHz

$IF_x = 435$ kHz is attenuated by the two IF stages that are tuned to 455 kHz.

(c) $f_i = 15{,}000 + 2(455) = 15{,}000 + 910 = 15{,}910$ kHz

$IF_i = f_i - f_o = 15{,}910 - 15{,}455 = 455$ kHz

Since $IF_i = IF = 455$ kHz, the IF stages will not block IF_i. The image frequency f_i has to blocked by the two RF stages and the mixer.

(d) For good rejection of the image frequency the IF frequency should be high. However, increasing the IF reduces the rejection of the nearby interferring signal f_x. For good rejection of both f_i

14.15 (concl.)

and f_x a double conversion superhet receiver should be used. See Prob 14.16 and Fig P 14.16 (c).

14.16 (a) $f_1 = 150{,}010$ kHz ; $f_2 = 150{,}910$ kHz

Rec. in Fig P14.16(a)

$IF(f_1) = 150{,}455 - 150{,}010 = 445$ kHz (GOOD IF REJECTION)

$IF(f_2) = 150{,}910 - 150{,}455 = 455$ kHz (NO IF REJECTION)

Any attenuation of f_2 must occur in the RF and Mixer stages. This receiver will have bad image frequency interference

Rec in Fig P14.16(b)

$IF(f_1) = 150{,}010 - 140{,}000 = 10{,}010$ kHz (POOR IF REJECTION)

$IF(f_2) = 150{,}910 - 140{,}000 = 10{,}910$ kHz (GOOD IF REJECTION)

Attenuation of nearby frequencies – such as f_1 – is very poor. Receiver has good image frequency rejection.

Rec in Fig P14.16(c)

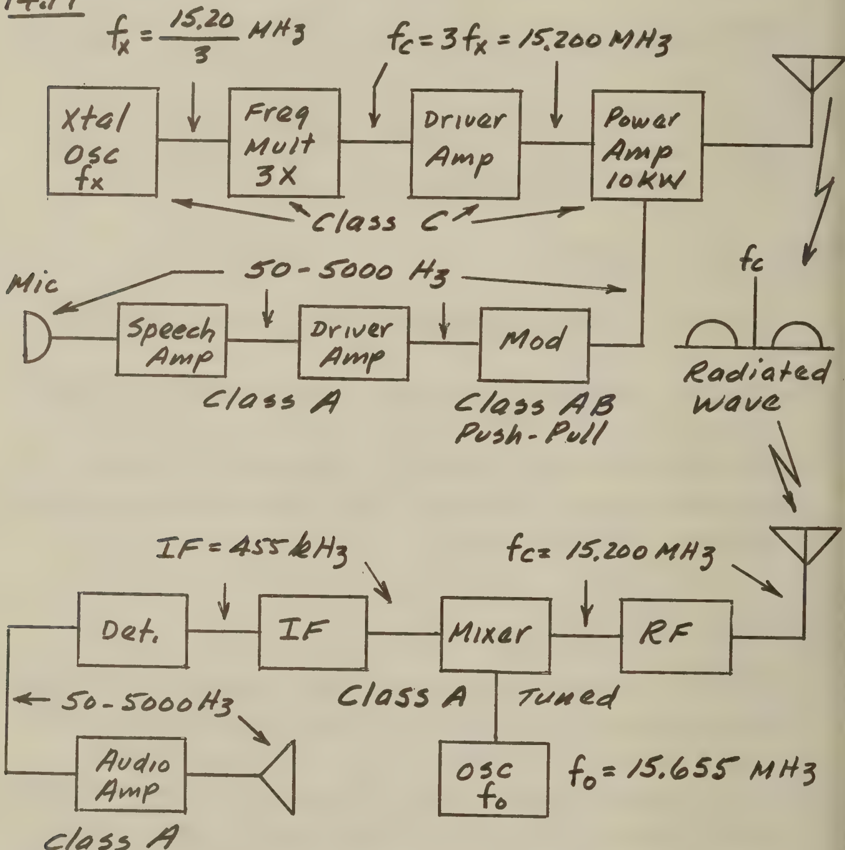
This receiver combines the good qualifies of the receivers in Figs P14.16(a) and (b):

(1) The $IF_1 = 10{,}000$ kHz stages provide excellent image frequency rejection.
(2) The $IF_2 = 455$ kHz stages provide excellent nearby frequency rejection.

14.16 (Concl.)

(b) At frequencies above 50 MHz we cannot obtain both nearby frequency and image frequency rejection using a single IF frequency. Double conversion superhets are mandatory in modern communications systems because of the over crowded conditions throughout the radio frequency spectrum.

14.17



CHAPTER 15

15.1 From a table of Bessel Functions we obtain

$$\left.\begin{aligned} J_{14}(10) &= 0.0119 \\ J_{15}(10) &= 0.0045 \end{aligned}\right\} \quad F_B = \frac{n}{m_f} = \frac{14}{10} = 1.40$$

$$\left.\begin{aligned} J_{24}(20) &= 0.1993 \\ J_{25}(20) &= 0.00978 \end{aligned}\right\} \quad F_B = \frac{n}{m_f} = \frac{24}{20} = 1.20$$

15.2

(a) $B_H = 2\Delta f\, F_B$; $F_B = \dfrac{200}{2 \times 75} = 1.33$

From Fig 15.2, $m_f \doteq 12$ radians

$m_f = \dfrac{\Delta f}{f_s}$; $f_s = \dfrac{75}{12} = 6.25$ kHz

(b) $m_f = \dfrac{75}{10} = 7.5$ radians

From Fig 15.2, $F_B \doteq 1.5$

$B_H = 2 \times 75 \times 1.5 = 225$ kHz (Exceeds FCC Reg.)

15.3 1 volt audio produces $\Delta f = 6$ kHz in modulator.

$\Delta f_1 = 0.40 \times 6 = 2.4$ kHz ; $12\Delta f_1 = 12 \times 2.4 = 28.8$ kHz
$\Delta f_2 = 0.80 \times 6 = 4.8$ " ; $12\Delta f_2 = 12 \times 4.8 = 57.6$ "
$\Delta f_3 = 0.80 \times 6 = 4.8$ " ; $12\Delta f_3 = 12 \times 4.8 = 57.6$ "
$\Delta f_4 = 0.20 \times 6 = 1.2$ " ; $12\Delta f_4 = 12 \times 1.2 = 14.4$ "

15.3 (Concl.)

$m_{f1} = \frac{28.8}{0.50} = 57.6$ radians ; $BW_1 = 2 \times 28.8 \times 1.05 = 60.5$

$m_{f2} = \frac{57.6}{1.0} = 57.6$ " ; $BW_2 = 2 \times 57.6 \times 1.05 = 121.0$

$m_{f3} = \frac{57.6}{3} = 19.2$ " ; $BW_3 = 2 \times 57.6 \times 1.20 = 138.5$

$m_{f4} = \frac{14.4}{10} = 1.44$ " ; $BW_4 = 2 \times 14.4 \times 2.5 = 72.0$

$BW_1 = 61$ kHz ; No. side freq = 122

$BW_2 = 122$ " ; " " " = 122

$BW_3 = 138$ " ; " " " = 46

$BW_4 = 80$ " ; " " " = 8

15.4 1 volt audio produces $m_p = 6$ rad in Xtal osc.

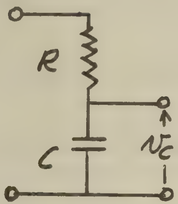
$m_{p1} = 0.40 \times 6 = 2.4$ rad ; $\Delta f_1 = 2.4 \times 0.50 = 1.20$ kHz
$m_{p2} = 0.80 \times 6 = 4.8$ " ; $\Delta f_2 = 4.8 \times 1.0 = 4.80$ "
$m_{p3} = 0.80 \times 6 = 4.8$ " ; $\Delta f_3 = 4.8 \times 3.0 = 14.40$ "
$m_{p4} = 0.20 \times 6 = 1.2$ " ; $\Delta f_4 = 1.2 \times 10 = 12.00$ "

$12 \Delta f_1 = 12 \times 1.20 = 14.40$ kHz ; $12 m_{p1} = 28.8$ rad
$12 \Delta f_2 = 12 \times 4.80 = 57.60$ " ; $12 m_{p2} = 57.6$ "
$12 \Delta f_3 = 12 \times 14.40 = 172.80$ " ; $12 m_{p3} = 57.6$ "
$12 \Delta f_4 = 12 \times 12.00 = 144.00$ " ; $12 m_{p4} = 14.4$ "

$B_{H1} = 2 \times 14.4 \times 1.13 = 32.5$
$B_{H2} = 2 \times 57.6 \times 1.08 = 124.5$
$B_{H3} = 2 \times 172.80 \times 1.08 = 373$
$B_{H4} = 2 \times 144 \times 1.25 = 360$

$B_{H1} = 32$ kHz ; 64 side freq
$B_{H2} = 124$ " ; 124 "
$B_{H3} = 372$ " ; 124 "
$B_{H4} = 360$ " ; 36 "

15.5



$$v_C = 0.80\cos 1000\pi t + 0.80\cos 2000\pi t + \frac{0.80}{3}\cos 6000\pi t + \frac{0.20}{10}\cos 20{,}000\pi t$$

$m_{p1} = 0.80\times 6 = 4.8$ rad ; $\Delta f_1 = 4.8\times 0.5 = 2.4$ kHz
$m_{p2} = 0.80\times 6 = 4.8$ " ; $\Delta f_2 = 4.8\times 1.0 = 4.8$ "
$m_{p3} = \frac{0.80}{3}\times 6 = 1.6$ " ; $\Delta f_3 = 1.6\times 3.0 = 4.8$ "
$m_{p4} = \frac{0.20\times 6}{10} = 0.12$ " ; $\Delta f_4 = 0.12\times 10 = 1.2$ "

Since the frequency deviations are the same as those for the FM system in Prob. 15.3, the bandwidths and number of side frequencies are also the same.

15.6 For the simplified reactance modulator circuit of Fig 15.5(b),

$$I = I_1 + I_c \qquad R = R_1 \,||\, h_{ie}$$

$$I_1 = \frac{E_{12}}{R - jX_1} \doteq \frac{jE_{12}}{X_1} \quad (X_1 \gg R)$$

$$I_c = h_{fe} I_b = \frac{h_{fe} I_1 R_1}{R_1 + h_{ie}} = k\, h_{fe} I_1$$

$$I = \frac{jE_{12}}{X_1} + k\,h_{fe} I_1 = j\frac{E_{12}}{X_1}[1 + k\,h_{fe}]$$

$$I = jE_{12}\,\omega C_1 [1 + k\,h_{fe}] = jE_{12}\,\omega C_{12}$$

$$C_{12} = [1 + k\,h_{fe}] C_1 \doteq k\,h_{fe} C_1$$

$$k = \frac{R_1}{R_1 + h_{ie}}$$

15.7 For the equivalent circuits of Fig 15.4 (d),

$$C_0 = C_b + [1 + g_{mo} R_1] C_1 = C_b + 5 + g_{mo}(500)(5)$$

$$g_{mo} = 3000 + 500\,(-3.5) = 3000 - 1750 = 1250\ \mu\mho$$

$$C_0 = C_b + 5 + 2500\,(1250 \times 10^{-6}) = C_b + 8.13\ \text{pf}$$

$$f_0 = \frac{1}{2\pi\sqrt{L_b C_0}}\ ;\ C_0 = \frac{1}{(2\pi)^2 (6\times 10^6)^2 \times 20 \times 10^{-6}}$$

$$C_0 = 35.10\ \text{pf}\ ;\ C_b = 35.10 - 8.13 \doteq 26.9\ \text{pf}$$

$$\Delta f \doteq -\frac{\Delta C f_c}{2C_0} \quad (\text{Eq } (15.18) \text{ page } 765)$$

$$\Delta C = -\frac{2\Delta f\, C_0}{f_0} = \frac{-2 \times 2 \times 35.10}{6000} = -0.0234\ \text{pf}$$

$$\Delta C = \Delta g_m R_1 C_1\ ;\ \Delta g_m = \frac{0.0234}{500 \times 5} = 9.4\ \mu\mho$$

$$g_m = 3000 + 500\, e_c\ \mu\mho$$

$$\frac{\Delta g_m}{\Delta e_c} = 500\ \mu\mho/\text{volt}$$

$$\Delta e_c = \frac{\Delta g_m}{500} = \frac{9.4}{500} = 0.0187\ \text{V}\ ;\ E_{sm} = 0.0187\ \text{V}$$

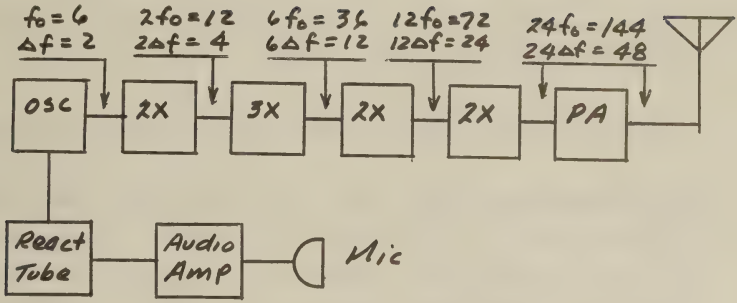
(c) $\Delta f(\text{osc}) = 2\ \text{kHz}\ ;\ 24\,\Delta f(\text{osc}) = 48\ \text{kHz}$

$$m_f = \frac{48}{1} = 48\ \text{radians}\ ;\ F_B \doteq 1.08$$

$$B_H = 2 \times 48 \times 1.08 \doteq 104\ \text{kHz}$$

15.7 (Concl.)

(d)



15.8 (a) For the simplified varactor circuit of Fig 15.5(d),

From the solution of Prob. 5.7,

$$C_o = 35.10 \text{ pf} ; \qquad C_b = 35.10 - 6.8 = 28.3 \text{ pf}$$

(b) $$\Delta C = \frac{-2 \times 35.10 \times 2}{6000} = -0.0234 \text{ pf} \quad (\text{same as Prob 15.7})$$

$$\Delta C = -0.80\,\Delta V_r = -(-0.0234)$$

$$\Delta V_r = \frac{0.0234}{0.8} = 0.0292 \text{ V}$$

(c) and (d) Solution and results same as those in Prob 15.8. Reactance Tube is replaced with the Varactor circuit of Fig 15.5 (c).

15.9 (a)

$$\phi(t) = \int^{t} W_c\,dt + \phi_o + k_p e_s \quad (\text{From Eq } (15.9))$$

$$\phi(t) = W_c t + \phi_o + k_p E_{sm} \sin W_s t$$

$$= W_c t + m_p \sin W_s t \; ; \quad m_p = k_p E_{sm}$$

15.9 (Concl.)

This expression for $\phi(t)$ is the same as that in Eq (15.4) for $\phi(t)$ for FM.

$$i(t) = I_{cm} \cos \phi(t) = I_{cm} \cos[\omega_c t + m_p \sin \omega_s t]$$

If we replace m_p with m_f we get the FM expression in Eq (15.5) for $i(t)$. The expression for $i(t)$ given in Eq (15.7), therefore, represents $i(t)$ for the PM system if m_f is replaced with m_p.

(b) For $m_p = 0.50$: $J_0(0.50) = 0.9385$
$J_1(0.50) = 0.2423$
$J_2(0.50) = 0.0306$
$J_3(0.50) = 0.0044$

For $m_p < 0.50$, it appears reasonable to neglect all side frequencies beyond the first pair. The expression for $i(t)$ for $m_p = 0.50$ is

$$\begin{aligned} i(t) = I_{cm}[0.9385 \cos \omega_c t &+ 0.2423 \cos(\omega_c + \omega_s)t \\ &- 0.2423 \cos(\omega_c - \omega_s)t \\ &+ 0.0306 \cos(\omega_c + 2\omega_s)t \\ &+ 0.0306 \cos(\omega_c - 2\omega_s)t] \end{aligned}$$

For $m_p < 0.50$, the expression for $i(t)$ is the same as that for an AM signal. This is called narrow-band PM.

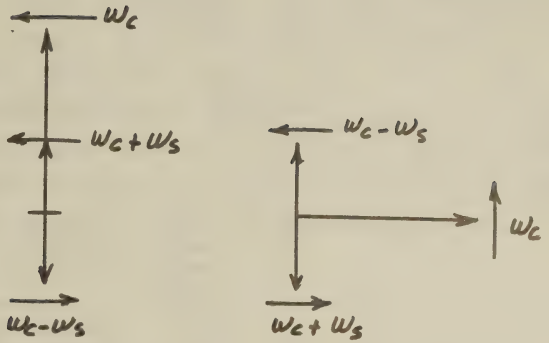
15.10 (a) $i(t) = [I_{cm} + I_{sm} \sin \omega_s t] \sin \omega_c t$

$$= I_{cm}[1 + m_a \sin \omega_s t] \sin \omega_c t$$

$$= I_{cm}\left[\sin \omega_c t - \frac{m_a}{2} \cos(\omega_c + \omega_s)t + \frac{m_a}{2} \cos(\omega_c - \omega_s)t\right]$$

15.10 (Concl.)

(b)



PM Phasor Diagram AM Phasor Diagram

(c) If we shift the AM carrier by 90°, we then have a phasor diagram identical to the PM phasor diagram. The system shown in Fig P15.11 is known as the Armstrong phase shift modulator. In this system the output of the balanced modulator is a DSBsc (see page 726) wave; it is combined in the Adding Network with the carrier f_c after the carrier is shifted by 90° to produce a narrow band PM output. Only AM procedures are used in this system.

15.11 Partial explanation is given in Prob 15.10.

Balanced Modulator: Generates the double sideband suppressed carrier signal (see page 726)

Phase Shift 90°: Shifts the carrier f_c by 90°.

Adder Network: Combines the 90° shifted carrier with the DSBsc signal.

15.12 (a) $m_p' = \dfrac{\Delta f}{f_s} = \dfrac{75 \times 10^3}{50} = 1500$ radians

$$m_p' = \frac{75 \times 10^3}{15{,}000} = 5 \text{ radians}$$

(b)

For $f_s = 50\ Hz$: $\dfrac{m_p'}{m_p} = \dfrac{1500}{0.50} = 3000$

$$\frac{f_c'}{f_c} = \frac{92.10 \times 10^6}{200 \times 10^3} = 460.50$$

No, because we need a multiplication of 3000 to obtain the desired m_p' of 1500 radians.

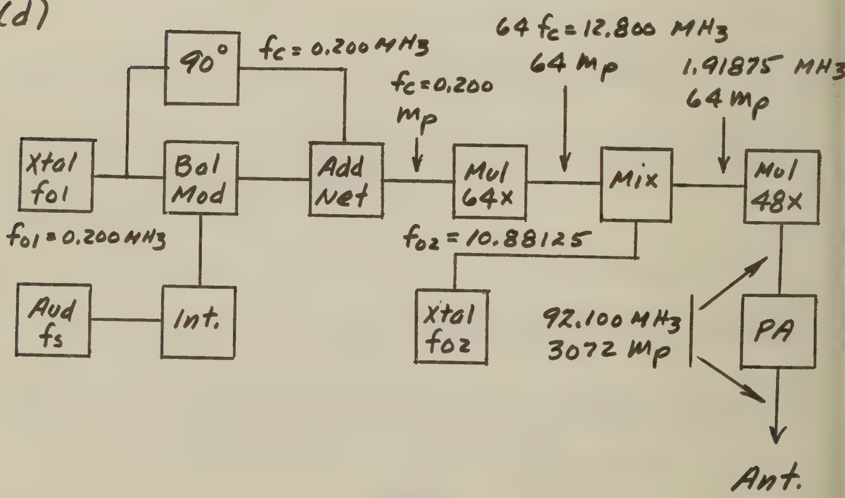
(c)

$$0.200 \times 64 = 12.800\ MHz$$

$$\frac{92.100}{48} = 1.91875\ MHz$$

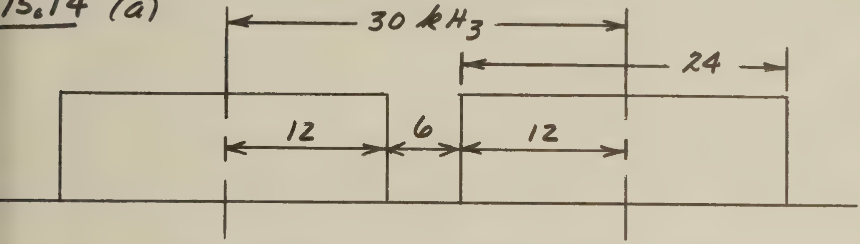
$$f_{osc.2} = 12.80 - 1.91875 = 10.88125\ MHz$$

(d)



15.13 With a $B_H = 200$ kHz the circuit Q's would range from 2.75 to 8. These values would not provide sufficient selectivity. Also with a B_H of 200 kHz there would only be room for 5 channels. FM in the standard broadcast band of 550 to 1600 kHz is not practical.

15.14 (a)



$f_{c1} = 152{,}030$ kHz $f_{c2} = 152{,}060$ kHz

$m_{f2} = \dfrac{5000}{3000} = 1.67$; $B_{H2} = 2 \times 5 \times 2.30 = 24$ kHz

$m_{f1} = \dfrac{5000}{300} = 16.7$; $B_{H1} = 2 \times 5 \times 1.20 = 12$ kHz

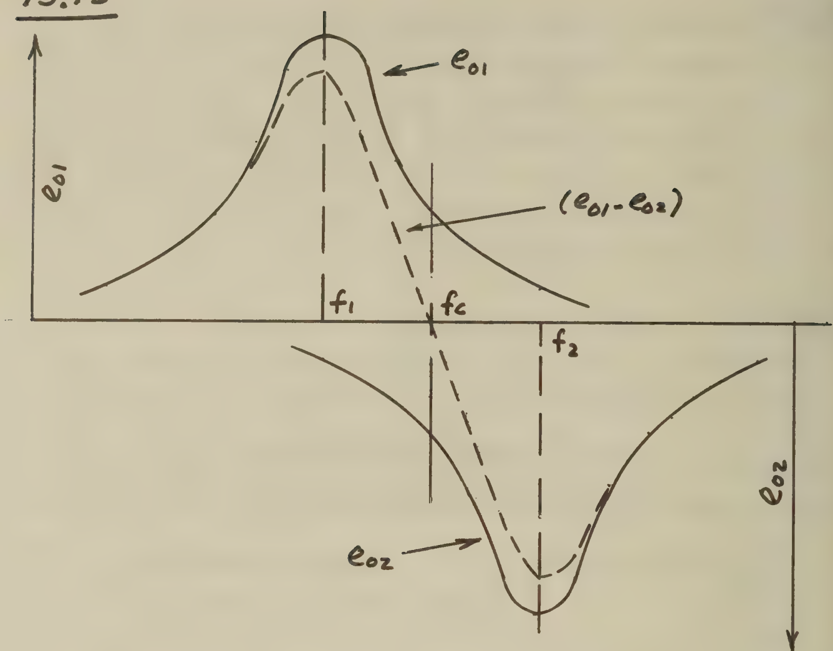
(b) Guard Band $= 30 - 24 = 6$ kHz

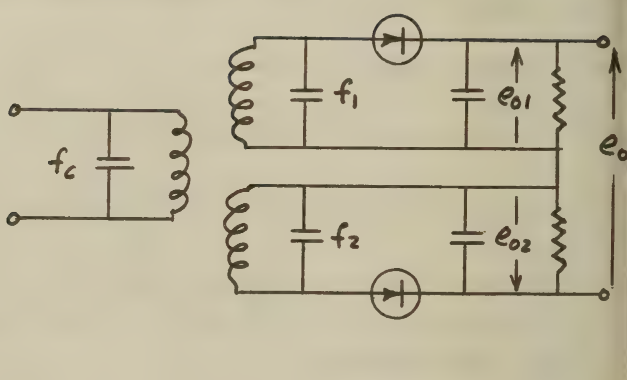
(c) $f_{c1} = 152{,}030\,[1 + 0.0005\%] = 152{,}030 + 0.760$

$f_{c2} = 152{,}060\,[1 - 0.0005\%] = 152{,}060 - 0.760$

Guard Band is decreased by (2×0.760) to a value of 4.48 kHz. Side frequencies do not overlap.

15.15





15.16 $$\theta(t) = \tan^{-1}\frac{m\sin\omega_d t}{1+m\cos\omega_d t} \qquad (15.31)$$

$$\frac{d\theta}{dt} = \frac{d}{dt}\tan^{-1}u = \frac{1}{1+u^2}\,\frac{du}{dt} \;;\quad u = \frac{m\sin\omega_d t}{1+m\cos\omega_d t}$$

$$\frac{du}{dt} = \frac{m\omega_d\,[m+\cos\omega_d t]}{[1+m\cos\omega_d t]^2}$$

$$\frac{d\theta}{dt} = \frac{1}{1+\frac{[m\sin\omega_d t]^2}{[1+m\cos\omega_d t]^2}} \cdot \frac{m\omega_d\,[m+\cos\omega_d t]}{[1+m\cos\omega_d t]^2}$$

$$= \frac{m\omega_d\,[m+\cos\omega_d t]}{[1+m\cos\omega_d t]^2+[m\sin\omega_d t]^2}$$

$$= \frac{m\omega_d\,[m+\cos\omega_d t]}{1+2m\cos\omega_d t+m^2}$$

CHAPTER 16

16.1 $$i_C = -I_{CO}[\exp(v_{CB}/\phi)-1] + \alpha_N i_E \qquad Eq\ (16.2)$$

$$v_{CB} = \phi\ln\left[\frac{-i_C+I_{CO}+\alpha_N i_E}{I_{CO}}\right]$$

$$i_E = I_{EO}[\exp(v_{EB}/\phi)-1] + \alpha_I i_C \qquad Eq\ (16.2)$$

$$v_{EB} = \phi\ln\left[\frac{i_E+I_{EO}-\alpha_I i_C}{I_{EO}}\right] \quad \text{and} \quad v_{CE} = v_{CB}-v_{EB}$$

16.2 From Eq (16.2),

$$i_C = I_{CO} + \alpha_N i_E$$

$$i_E = -I_{EO} + \alpha_I i_C$$

$$i_C = I_{CO} - \alpha_N I_{EO} + \alpha_N \alpha_I i_C$$

$\alpha_N = 0.98$
$I_{CO} = 1\times10^{-7}\ a$

$\alpha_I = 0.49$
$I_{EO} = 0.50\times10^{-7}\ a$

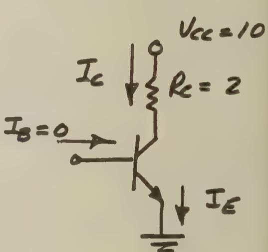
$$i_C = \frac{I_{CO} - \alpha_N I_{EO}}{1-\alpha_N\alpha_I}$$

$$i_C = \frac{1\times10^{-7} - 0.98(0.50\times10^{-7})}{1-0.98\times0.49} = 0.098\ \mu a$$

$$i_E = \frac{-I_{EO} + \alpha_I I_{CO}}{1-\alpha_N\alpha_I}$$

$$i_E = \frac{-0.50\times10^{-7} + 0.49\times10^{-7}}{1-0.98\times0.49} = \frac{-0.01\times10^{-7}}{0.52} = -0.0019\ \mu a$$

16.3 (a) $I_B = 0$; $I_C = I_E$



$$I_C = I_{CO} + \alpha_N I_E = I_{CO} + \alpha_N I_C$$

$$I_C = I_E = \frac{I_{CO}}{1-\alpha_N} = \frac{1}{1-0.98} = 50\ \mu a$$

(b) From Prob. 16.2,

$$I_C = \frac{I_{CO} - \alpha_N I_{EO}}{1-\alpha_N\alpha_I} = \frac{1-0.98(0.41)}{1-0.98\times0.40} = 0.985\ \mu a$$

$$I_E = \frac{-I_{EO} + \alpha_I I_{CO}}{1-\alpha_N\alpha_I} = \frac{-0.41+0.40(1)}{1-0.98\times0.40} = -0.0164\ \mu a$$

(c) $I_E = I_{EO}[\exp(0)-1] + \alpha_I I_C = \alpha_I I_C$

$$I_C = I_{CO} + \alpha_N\alpha_I I_C$$

$$I_C = \frac{I_{CO}}{1-\alpha_N\alpha_I} = \frac{1}{1-0.98\times0.40} = 1.65\ \mu a$$

$I_E = 0.40(1.65)$
$= 0.66\ \mu a$
$I_B \doteq 0.99\ \mu a$

16.4 (a)

$$I_{CA} \doteq \frac{V_{CC}}{R_C} = \frac{10}{1} = 10 \text{ ma}$$

$\alpha_N = 0.98$
$I_{CO} = 1\ \mu a$
$\alpha_I = 0.40$
$I_{EO} = 0.41\ \mu a$

$$I_{BA} = \frac{(1-\alpha_N) I_{CA}}{\alpha_N} - \frac{I_{CO}}{\alpha_N}$$

$$= \frac{(1-0.98)(10)}{0.98} - \frac{1\times10^{-3}}{0.98} = \frac{10}{49} - \frac{1\times10^{-3}}{0.98} \text{ ma}$$

$I_{BA} = 0.203$ ma $= 203\ \mu a$; $I_{EA} = 10.203$ ma

(b) $V_{CBA} = 0$

$$V_{EB} = -25 \ln \left[\frac{10.2 + 0.00041 - 4}{0.41\times10^{-3}}\right]$$

$$= -25 \ln 15.2\times10^{3} = -25(9.64) = -241 \text{ mv}$$

$$V_{CE} = V_{CB} - V_{EB} = 0 - (-241) = 241 \text{ mv}$$

(c) overdrive $n = 3$: $I_{BX} = 3 \times 203 = 609\ \mu a$

$$I_{CX} \doteq \frac{V_{CC}}{R_C} = I_{CA} = 10 \text{ ma}$$

$$I_{EX} = 10.609 \text{ ma}$$

$$V_{EB} = -25 \ln \left[\frac{10.6 - 0.40(10)}{0.41\times10^{-3}}\right] = -25 \ln 16.1\times10^{3}$$

$$= -25(9.7) = -243 \text{ mv}$$

$$V_{CB} = -25 \ln \left[\frac{-10 + 0.98(10.6)}{1\times10^{-3}}\right] = -25 \ln 400$$

$$V_{CB} = -25(6) = -150 \text{ mv}$$

$$V_{CE} = V_{CB} - V_{EB} = -150 + 243 = 93 \text{ mv}$$

16.5

$$q_{T0} = I_{B1} t_d = 1\times10^{-3} \times 20\times10^{-9} = 20\times10^{-12} \text{ coulombs}$$

$$n = \frac{I_{B1}}{I_{CA}/h_{FE}} = \frac{1}{10/50} = 5$$

$$t_r = \tau_{BF} \ln\left[\frac{1-0.10/n}{1-0.90/n}\right] = \tau_{BF} \ln\left[\frac{1-0.10/5}{1-0.90/5}\right]$$

$$\tau_{BF} = \frac{t_r}{\ln[1.20]} = \frac{35}{0.182} = 192 \text{ ns}$$

$$\tau_F = \frac{\tau_{BF}}{h_{FE}} = \frac{192}{50} = 3.84 \text{ ns}$$

$$t_s = \tau_s \ln\left[\frac{n+m}{1+m}\right] = \tau_s \ln\left[\frac{5+5}{1+5}\right]$$

$$\tau_s = \frac{t_s}{\ln[1.67]} = \frac{50}{0.513} = 98 \text{ ns}$$

$$t_f = \tau_{BF} \ln\left[\frac{1+0.90/m}{1+0.10/m}\right] = 192 \ln\left[\frac{1+0.90/5}{1+0.10/m}\right]$$

$$= 192 \ln[1.155] = 192\times0.144 = 27.6 \text{ ns}$$

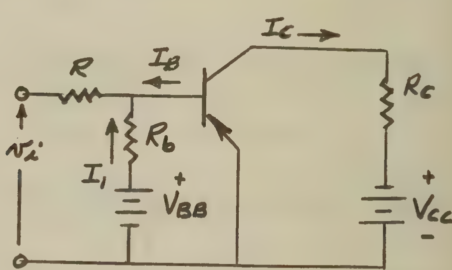
16.6

$I_c = 10$ ma

$I_{B1} = 1$ ma

$I_{B2} = -1$ ma

$\left.\begin{array}{l} V_{CE} = -250 \text{ mv} \\ V_{BE} = -300 \text{ mv} \end{array}\right\} \begin{array}{l} I_c = 10 \\ I_B = 1 \end{array}$



Select: $V_{cc} = -10$ V

$V_{BB} = 10$ V

16.6 (concl.)

$$R_C = \frac{V_{CC}}{I_C} = \frac{10}{10} = 1\ k\Omega$$

Cutoff value $V_{BE} \geq 2.0$ V (when $v_i = 0$)

$$V_{BE} = \frac{R\,V_{BB}}{R + R_b} = \frac{10R}{R + R_b} \geq 2\ V$$

SELECT $R = 5.1\ k\Omega$ and $R_b = 20\ k\Omega$

$$V_{BE} = \frac{10 \times 5.1}{5.1 + 20} = 2.03\ V$$

Saturation values:

$$v_i(\text{sat.}) = V_{BE} - R(I_B + I_1)$$

$$I_1 = \frac{V_{BB} - V_{BE}}{R_b} = \frac{10 + 0.30}{20} = 0.515\ ma$$

$$v_i(\text{sat.}) = -0.30 - 5.1(1.0 + 0.515) = -8.03\ V$$

The waveforms of i_B and i_C are of the same forms as those shown in Fig 16.3(a).

16.7 Correction: change $(\bar{A}B + AB)C$ to $(\bar{A}\bar{B} + AB)C$

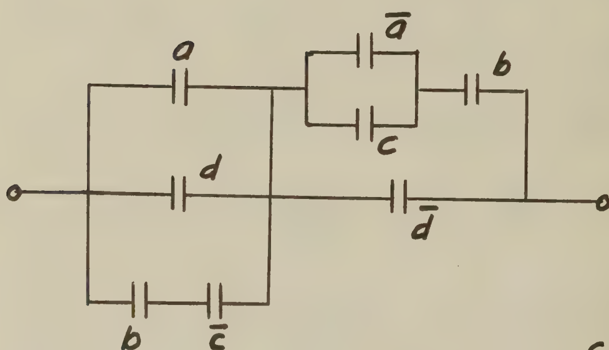
A	B	C	$(A\bar{B}+\bar{A}B)\bar{C}$	$(\bar{A}\bar{B}+AB)C$	Y
0	0	0	0	0	0
0	0	1	0	1	1
0	1	0	1	0	1
0	1	1	0	0	0
1	0	0	1	0	1
1	0	1	0	0	0
1	1	0	0	0	0
1	1	1	0	1	1

16.8

A	B	$\bar{A}$	$\bar{B}$	AB	$\overline{AB}$	$\bar{A}+\bar{B}$
0	0	1	1	0	1	1
0	1	1	0	0	1	1
1	0	0	1	0	1	1
1	1	0	0	1	0	0

$\therefore \quad \bar{A}+\bar{B} = \overline{AB}$

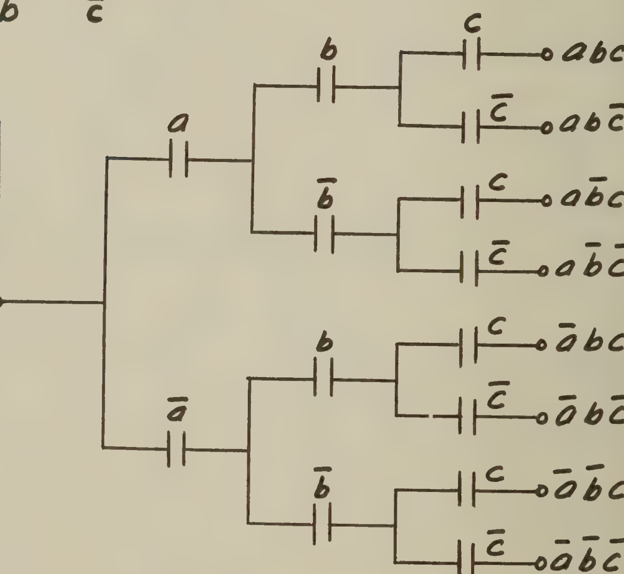
16.9



16.10

Correction

$a\overline{bc}$ to $a\bar{b}\bar{c}$
$\overline{ab}c$ to $\bar{a}\bar{b}c$
$\overline{abc}$ to $\bar{a}\bar{b}\bar{c}$



16.11 (a) & (b)

From the adjacent truth table we see that

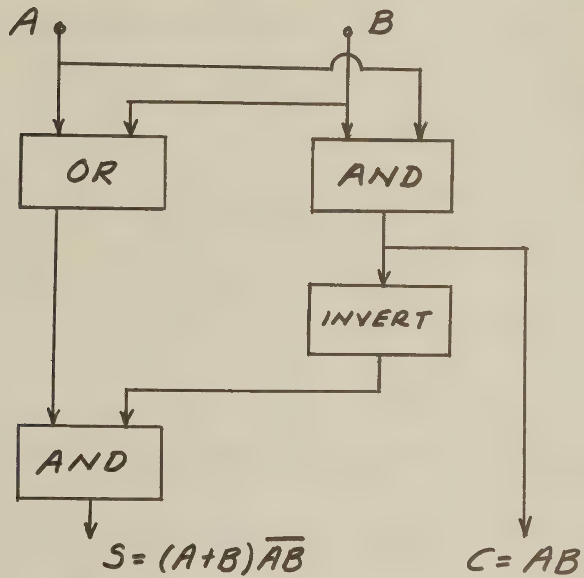
A	B	S	C
1	1	0	1
0	1	1	0
1	0	1	0
0	0	0	0

$C = AB$

$S = \bar{A}B + A\bar{B}$

$= (A+B)(\bar{A}+\bar{B}) = (A+B)\overline{AB}$

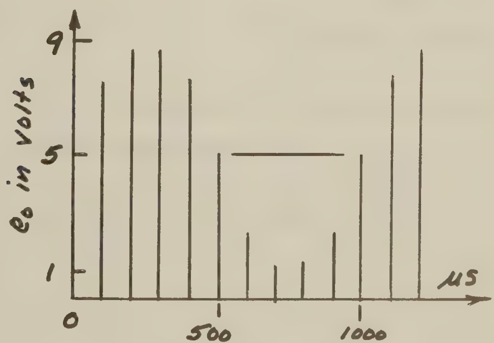
(c)



16.12

e_o is a series of $1\mu s$ pulses spaced $100\mu s$ apart.

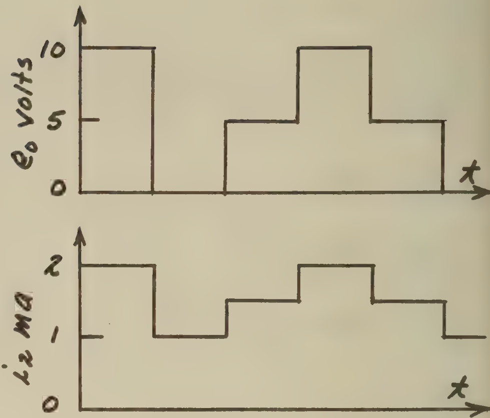
Yes, see Section 14.7 on sampling.



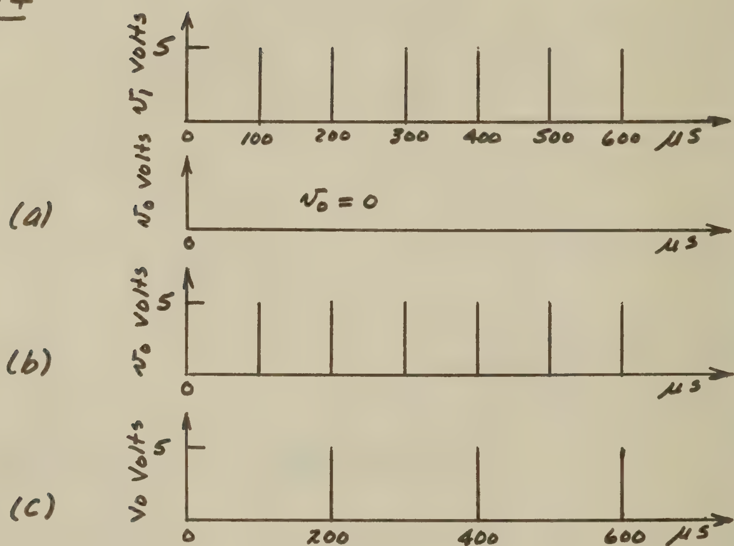
16.13

e_o is equal to the largest input voltage.

$$i_Z = \frac{e_o + 10}{10} \quad ma$$



16.14



When diode D conducts, $v_o = v_2$.
" " D non-conducting, $v_o = v_1$.

16.15 (a) $R_b = 10\ k\Omega$

Cutoff state: $V_{BE} = -2.0\ v = \dfrac{-R_b V_2}{R_b + R_2} = \dfrac{-10 R_b}{R_b + R_2}$

$$R_2 = \frac{8 R_b}{2} = 4 \times 10 = 40\ k\Omega$$

Saturation state: $I_C = 5\ ma,\ I_B = 0.50,\ h_{FE} = 30$

$V_{CE} = 0.20\ v,\quad V_{BE} = 0.40\ V$

$$R_C = \frac{15 - 0.20}{5} = 2.96 \doteq 3\ k\Omega$$

$$I_1 = I_2 + I_B = \frac{V_1 - V_{BE}}{R_1 + R_b} = \frac{V_{BE} + V_2}{R_2} + I_B$$

$$I_1 = \frac{0.40 + 10}{40} + 0.50 = 0.26 + 0.50 = 0.76\ ma$$

$$R_1 + R_b = \frac{V_1 - V_{BE}}{I_1} = \frac{15 - 0.40}{0.76} = 19.20\ k\Omega$$

$$R_1 = 19.2 - 10 = 9.20\ k\Omega$$

(c)

$$e_1 = e_{01} = V_1 - R_1 I_1 = 15 - (9.20)(0.76) = 15 - 6.98 = 8.02\ V$$

also $\quad e_1 = \left[\dfrac{V_1 - V_{BE}}{R_1 + R_b}\right] R_b + V_{BE}$

$$= \left[\frac{15 - 0.40}{9.20 + 10}\right](10) + 0.40 = 7.65 + 0.40 = 8.05\ V$$

(d) R_b is necessary. Its function is to supply the cutoff voltage $V_{BE} = -2.0$ v. See the expression for V_{BE} at the top of this page.

16.16 (a) & (b) $R_b = 5\ k\Omega$

Cutoff state: $V_{BE} = -2.0\ V = \dfrac{-R_b V_2}{R_b + R_2} = \dfrac{-10 R_b}{R_b + R_2}$

$$R_2 = \frac{8 R_b}{2} = 4 \times 5 = 20\ k\Omega$$

$$I_2 = \frac{V_2}{R_b + R_2} = \frac{10}{5+20} = 0.40\ ma$$

Saturation state: $I_C = 5\ ma$, $I_B = 0.50\ ma$, $h_{FE} = 30$

$$V_{CE} = 0.20\ v, \quad V_{BE} = 0.40\ V$$

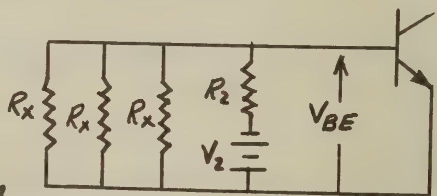
$$I_1 = I_2 + I_B = \frac{V_2 + V_{BE}}{R_2} + I_B = \frac{10 + 0.4}{20} + 0.50 = 1.02\ ma$$

$$e_1 = e_{01} = R_b I_1 + V_{BE} = 5(1.02) + 0.40 = 5.50\ V$$

$$R_C = \frac{15 - 0.20}{5} = 2.96 \doteq 3\ k\Omega$$

(d) R_b cannot be omitted. The cutoff voltage $V_{BE} = -2.0\ V$ is developed across R_b. See the expression for V_{BE} at the top of this page.

16.17 (a)



$$V_{BE} = \frac{-R_x' V_2}{R_2 + R_x'}$$

$$R_x' = \frac{R_x}{3} = \frac{4.70}{3} = 1.565\ k\Omega$$

$$V_{BE} = \frac{-1.565 \times 10}{27 + 1.565} = -0.547\ V$$

Transistor is cutoff.

16.17 (Concl.) (b)

Increasing the number of inputs decreases the value of

$$R_x' = \frac{R_x}{n} \quad \text{(where } n = \text{number of inputs)}$$

The current drain I_z on V_z is increased.

$$I_z = \frac{V_z}{R_z + R_x'}$$

The cutoff value of V_{BE} is decreased.

$$V_{BE} = \frac{-R_x' V_z}{R_z + R_x'}$$

The signal current I_s is increased.

$$I_s = I_B + \frac{V_{BE}}{R_x'} + \frac{V_z + V_{BE}}{R_z}$$

16.18 (a)

$$V_{BE} = \frac{-R_b V_{BB}}{R_b + R_1} \quad ; \quad R_b = \frac{-R_1 V_{BE}}{V_{BB} + V_{BE}}$$

$$R_b = \frac{20 \times 2}{10 - 2} = 5\ k\Omega \quad ; \quad R_c = \frac{10}{5} = 2\ k\Omega$$

(b)

$$v_o(OFF) \doteq \frac{R_L V_{CC}}{R_L + R_C} = \frac{10 \times 10}{10 + 2} = 8.33\ V$$

$$v_o(ON) = V_{CE}(sat.) = 0.20\ V$$

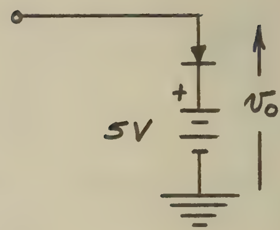
(c)

$$v_o(OFF) = \frac{5 \times 10}{5 + 2} = 7.07\ V \quad \text{(TWO 10 K}\Omega\text{)}$$

$$v_o(OFF) = \frac{2.5 \times 10}{2.5 + 2} = 5.55\ V \quad \text{(FOUR 10 K}\Omega\text{)}$$

16.18 (Concl.) (d)

$$v_o(\text{OFF}) = \frac{R_L' V_{CC}}{R_L' + R_C}$$



$$R_L' = \frac{R_C v_o}{V_{CC} - v_o} = \frac{2\times5}{10-2}$$

$R_L' = 2\,k\Omega$ where $R_L' = \frac{R_L}{n}$

$\therefore\ n = \frac{10}{2} = 5$ (number of 10 kΩ loads)

16.19

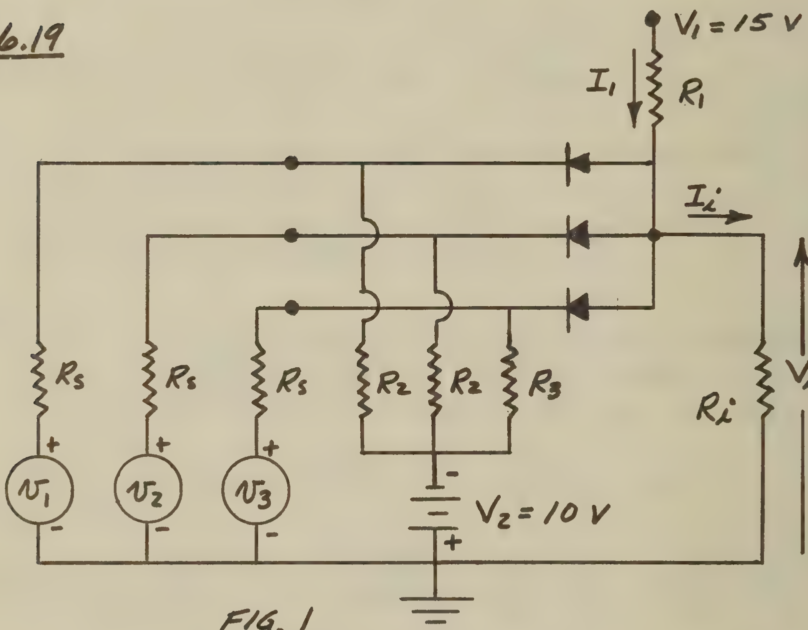


FIG. 1

Referring to Fig. 1, we note that resistance R_s of each signal source v_1, v_2, and v_3 is connected across R_i whenever its diode is conducting. For the moment let us assume R_s is very large so we can use the simplified circuit shown in Fig. 2.

16.19 (cont.)

$$V_1 = (R_1 + R_i) I_1 - R_i I_2$$

$$V_2 = -R_i I_1 + (R_2' + R_i) I_2$$

$$V_i = V_1 - R_1 I_1$$

Solving for I_1 and V_i, we obtain

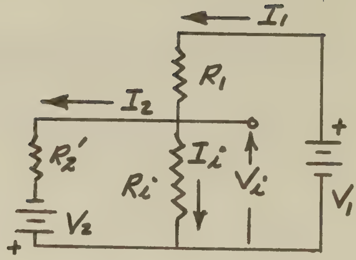


FIG. 2

$$I_1 = \frac{(R_2' + R_i) V_1 + R_i V_2}{(R_1 + R_i)(R_2' + R_i) - R_i^2}$$

$$V_i = \frac{R_i [R_2' V_1 - R_1 V_2]}{R_1 R_i + R_2'(R_1 + R_i)}$$

Where $R_2' = \frac{R_2}{n}$

n = number of conducting diodes

Assuming all diodes are non-conducting, we can determine R_1.

$$V_i = R_i I_i = 0.400 \times 1.0 = 0.40 \text{ V}$$

$$I_i = \frac{V_1}{R_1 + R_i} = \frac{15}{R_1 + 0.40} = 1 \text{ ma}$$

$$R_1 = \frac{15 - 0.40}{1} = 14.60 \text{ k}\Omega$$

Now consider the case where all diodes are conducting:

$v_1 = v_2 = v_3 = 0$; $V_i \leq -0.50$ V; $R_i = 100$ kΩ

$R_s' = \frac{R_s}{n} = \frac{R_s}{3}$ (affective resistance shunted across $R_i = 100$ kΩ).

In order for V_i to be negative, $R_1 V_2 > R_2' V$.

R_2' is a maximum when $n=1$, i.e., one diode is conducting.

$$R_2'(max) = \frac{R_2}{1} = R_2$$

Solving the expression for V_i for R_2', we get

$$R_2' = \frac{-R_i R_1 (V_2 + V_i)}{(R_1 + R_i) V_i - R_i V_1}$$

So as to include the effect of the input resistances, we will replace R_i with $R_i \| R_s'$. Let us assume that $R_s = 15\ k\Omega$; then

$$R_i \| R_s' = 100 \| \frac{15}{1} = 13\ k\Omega \qquad (\text{for } n=1)$$

$$R_2 = R_2' = \frac{-13 \times 14.6 \times 10^6 (10 - 0.50)}{(14.6+13)(10^3)(-0.50) - 13 \times 10^3 (15)} = 8.60\ k\Omega$$

$\therefore$ For $n=1$: $V_i = -0.50$ V

(c) Now consider case of 3 diodes conducting, i.e., $n=3$:

$$R_i \| R_s' = 100 \| \frac{15}{3} = 100 \| 5 = 4.76\ k\Omega$$

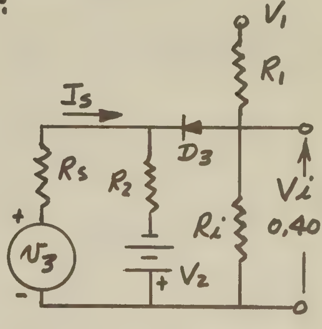
$$R_2' = \frac{R_2}{n} = \frac{8.60}{3} = 2.87\ k\Omega$$

$$V_i = \frac{4.76[2.87(15) - 14.6(10)]}{14.6 \times 4.76 + 2.87(14.6 + 4.76)} = \frac{4.76(-103)}{125}$$

$$= -3.92\ V$$

16.19 (concl.)

For $V_i = 0.40$ V the minimum value of input voltage v_3 (for diode #3) is determined as follows:



v_{D3} and i_{D3} are zero.

For D_3 to be cutoff

$$v_3 - R_s I_s \geq V_i = 0.40$$

$$v_3 \geq \frac{(R_s + R_2) V_i + R_s V_2}{R_2}$$

$$= \frac{0.40(15 + 8.60) + 15(10)}{8.60} = 18.50 \text{ V}$$

This value is quite large. Let us determine the values of R_2 and v_3 when R_s is reduced from 15 to 3 kΩ.

$$100 \,\|\, \frac{3}{1} = 2.91 \text{ k}\Omega \,; \quad R_2 = 7.70 \text{ k}\Omega$$

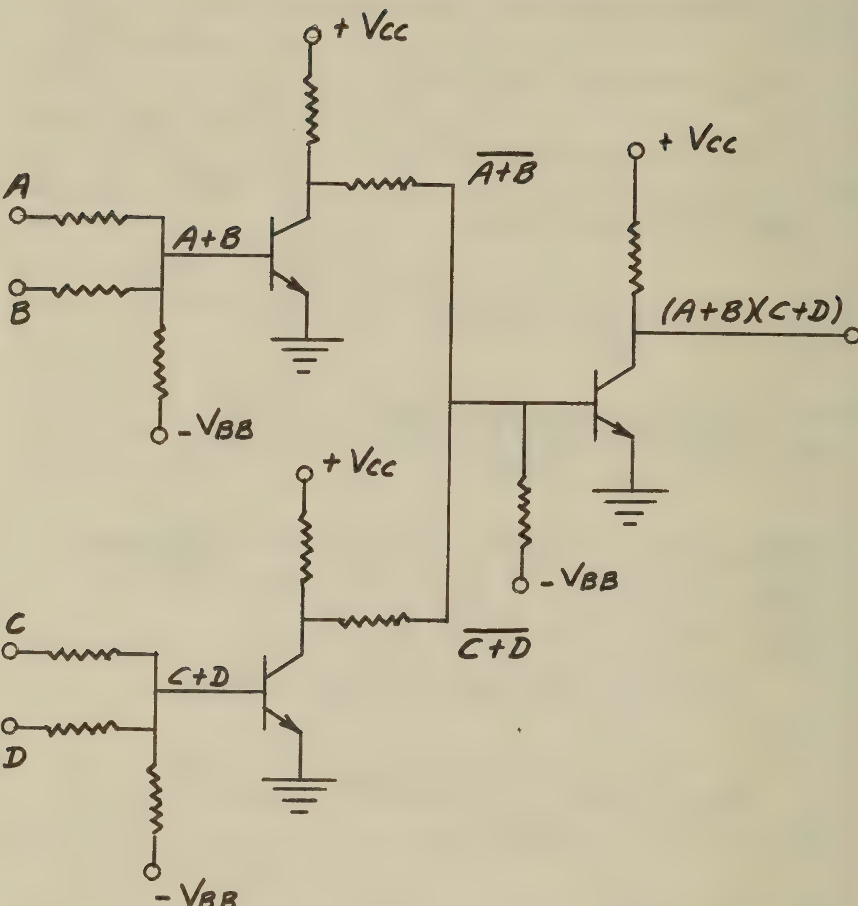
$$v_3 \geq \frac{0.40(3 + 7.70) + 3(10)}{7.70} = 4.45 \text{ V}$$

For $R_s = 300\,\Omega$:

$$R_2 = 3.48 \text{ k}\Omega$$

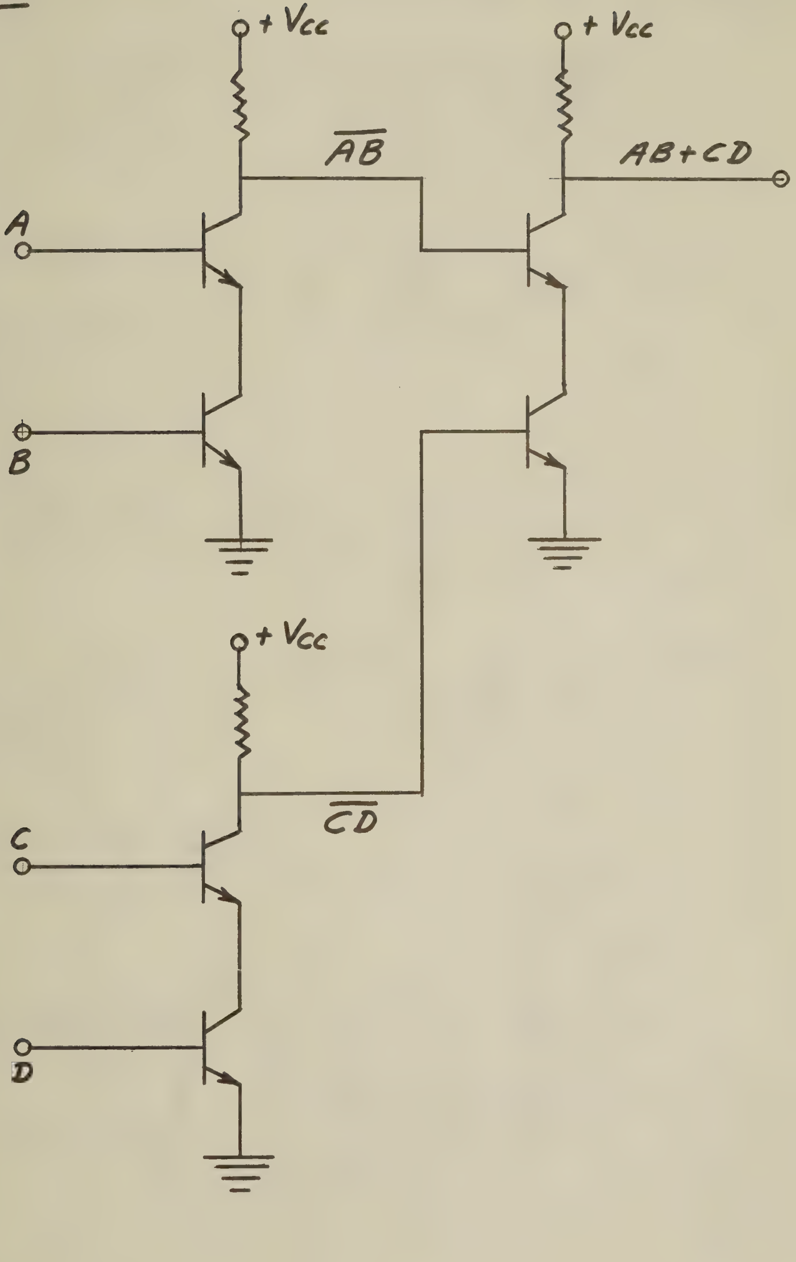
$$v_3 \geq 1.30 \text{ V}$$

16.20



+ Vcc
A
B
A+B
$\overline{A+B}$
- VBB
+ Vcc
(A+B)(C+D)
+ Vcc
- VBB
C
C+D
$\overline{C+D}$
D
- VBB

16.21



16.22 (a) For $A = B = C = D = 0$

$$V_{BE2} = \frac{-\frac{R_1}{2} V_2}{\frac{R_1}{2} + R_2} = \frac{-10 \times 10}{10 + 200} = -0.476 \text{ V}$$

$\therefore$ T_1 and T_2 are cutoff.

$$V_{CE1} = V_{CE2} \doteq \frac{V_{CC}}{2} = \frac{10}{2} = 5 \text{ V}$$

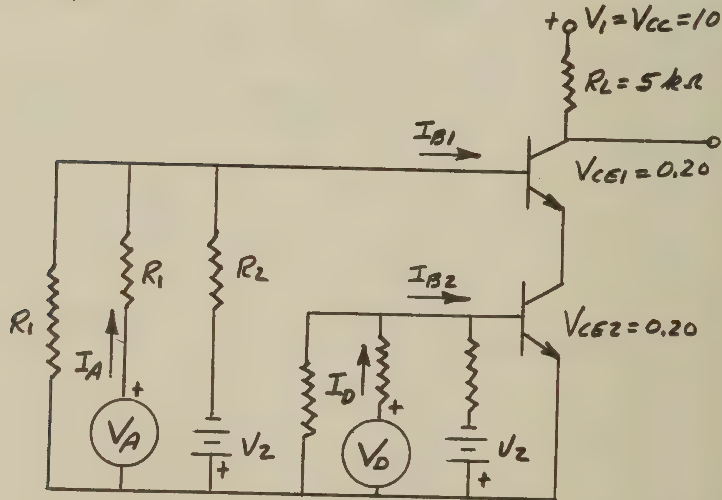
$$V_{BE1} = -0.476 - V_{CE2} = -0.476 - 5.0 = -5.476 \text{V}$$

$$I_{C1} = I_{C2} \doteq 0 \quad \text{and} \quad v_o \doteq V_{CC} = 10 \text{ V}$$

(b) For $A = 1$, $B = 0$, $C = 0$, $D = 1$: $V_{CE1} = V_{CE2} = 0.20 \text{ V}$

$$I_{C1} = I_{C2} \doteq \frac{V_1}{R_L} = \frac{10}{5} = 2 \text{ ma}$$

$$I_B = \frac{I_C}{h_{FE}} = \frac{2}{50} = 0.04 \text{ ma} = 40 \,\mu\text{a}$$



16.22 (concl.)

$$I_A = \frac{V_{BE1} + V_{CE2}}{R_1} + \frac{V_2 + V_{BE1} + V_{CE2}}{R_2} + I_{B1}$$

$$= \frac{0.60 + 0.20}{20} + \frac{10 + 0.60 + 0.20}{200} + 0.04 = 0.134 \text{ ma}$$

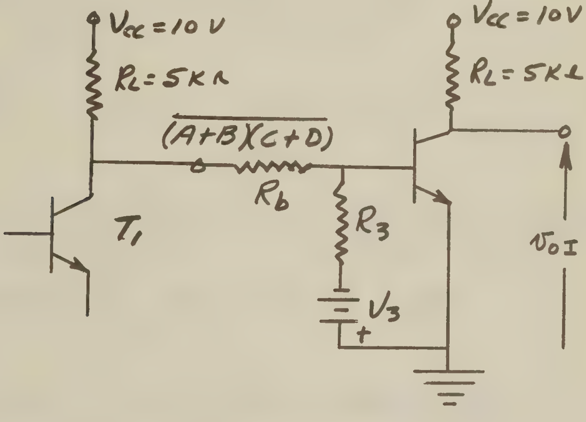
$$V_A = R_1 I_A + V_{BE1} + V_{CE2} = 20(0.134) + 0.60 + 0.20 = 3.48 \text{ V}$$

$$I_D = \frac{0.60}{20} + \frac{10.6}{200} + 0.04 = 0.123 \text{ ma}$$

$$V_D = 20(0.123) + 0.60 = 3.06 \text{ V}$$

(c) No. T_1 is cutoff, and since T_1 and T_2 are in series, the collector current I_{C2} of T_2 is limited to the cutoff value of I_{C1}.

(d)



Inverter output v_{OI} yields the following logic function:

$(A+B)(C+D)$

$A+B$	$C+D$	$(A+B)(C+D)$	v_{OI}
0	0	0	0.20 V
0	1	0	0.20 V
1	0	0	0.20 V
1	1	1	10.0 V

16.23 (a) Using the equivalent circuits and Symbols of Fig 16.11,

$$V_{eq} = 11.00\text{ V} \;;\quad R_{eq} = \frac{100(3+50)}{100+3+50} = 34.6\text{ k}\Omega$$

$$I_{B2} = \frac{V_{eq} - V_{BE}}{R_{eq}} = \frac{11.00 - 0.40}{34.6} = 0.306\text{ ma}$$

$$I_C = \frac{V_{CC} - V_{CE}}{R_C} = \frac{20 - 0.20}{3} = 6.60\text{ ma}$$

$$V_{BE1} = -\frac{R_d(V_{BB} + V_{CE2})}{R_b + R_d} + V_{CE2} = \frac{-50(4+0.20)}{100+50} + 0.20$$

$$= -1.40 + 0.20 = -1.20\text{ V}$$

$$V_{CE1} = \frac{R_d(V_{CC} - V_{CE2})}{R_c + R_d} = \frac{50(20-0.20)}{3+50} = 18.7\text{ V}$$

(b) $$h_{FE}(\min) = \frac{6.60}{0.306} = 21.6$$

(c) See self-biasing circuit of Fig 16.12(d).

$$V_{BB} \doteq R_e I_E \;;\quad R_e = \frac{4}{6.60+0.306} = 580\ \Omega$$

(d) See collector triggering circuit of Fig 16.12(b).

Reverse bias on D_1 is $-20 + 18.7 = -1.30$ V

" " " D_2 is $-20 + 0.20 = -19.8$ V

Application of a negative pulse of magnitude greater than 1.30 V and less than 19.8 will cause D_1 to conduct and D_2 to remain nonconducting.

16.24 From Eq (16.51) and Fig. 16.14, the collector voltage is

$$v_{CE}(t) = V_{CC}\left[1 - \exp(-t/R_C C)\right]$$

The rise time T_r (see page 444) is

$$T_r = 2.20\, R_c C$$

The ratio of T_r over the period is

$$\frac{T_r}{0.695\, R_b C} = \frac{2.20\, R_c C}{0.695\, R_b C}$$

$$I_{BX} = \frac{m V_{CC}}{h_{FE} R_c} = \frac{V_{CC}}{R_b}$$

$$R_b = \frac{h_{FE} R_c}{m}$$

$$\frac{T_r}{0.695\, R_b C} = \frac{2.20\, R_c m}{0.695\, h_{FE} R_c} = \frac{2.20\, m}{0.695\, h_{FE}} = \frac{3.17\, m}{h_{FE}}$$

16.25

$V_{CC} = 15\ \text{V}$, $I_{CA} = 5\ \text{ma}$, $h_{FE} = 50$

$$R_C = \frac{15}{5} = 3\ \text{k}\Omega\ , \quad I_{BA} = \frac{5}{50} = 0.100\ \text{ma} \quad (m=1)$$

$$R_b = \frac{V_{CC}}{I_{BA}} = \frac{15}{0.100} = 150\ \text{k}\Omega$$

$$t_2 = \frac{1}{2f_r} = \frac{1}{2 \times 15{,}750} = 0.317 \times 10^{-4} = 0.0317\ \text{ms}$$

16.25 (concl.)

$$C = \frac{t_2}{0.695 R_b} = \frac{0.0317 \times 10^{-3}}{0.695 \times 150 \times 10^3} = 305 \text{ pf}$$

$$\frac{T_r}{0.695 R_b C} = \frac{3.17 m}{h_{FE}} = \frac{3.17 (1)}{50} = 0.0634$$

16.26 (a)

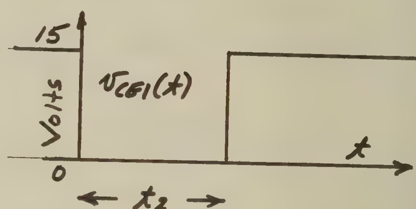
$$I_{C2} \doteq \frac{15}{3} = 5 \text{ ma} \; ; \; I_{BA} = \frac{5}{h_{FE}} = \frac{5}{50} = 0.100 \text{ ma}$$

$$I_{B2} = \frac{15}{75} = 0.200 \text{ ma} \; ; \; m = \frac{0.200}{0.100} = 2$$

$$V_{BE1} = \frac{-R_d V_{BB}}{R_{b1} + R_d} = \frac{-6 R_d}{150 + R_d}$$

Assume $V_{BE1} = -1.50$ V, then

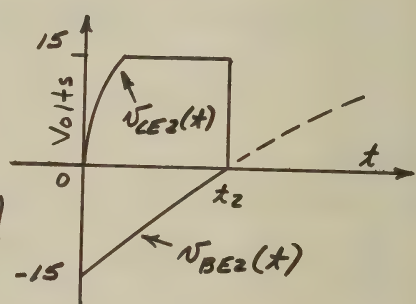
$$R_d = 50 \text{ k}\Omega$$



$$t_2 = 0.695 \times 75 \times 10^3 \times 575 \times 10^{-12}$$
$$= 0.030 \text{ ms}$$

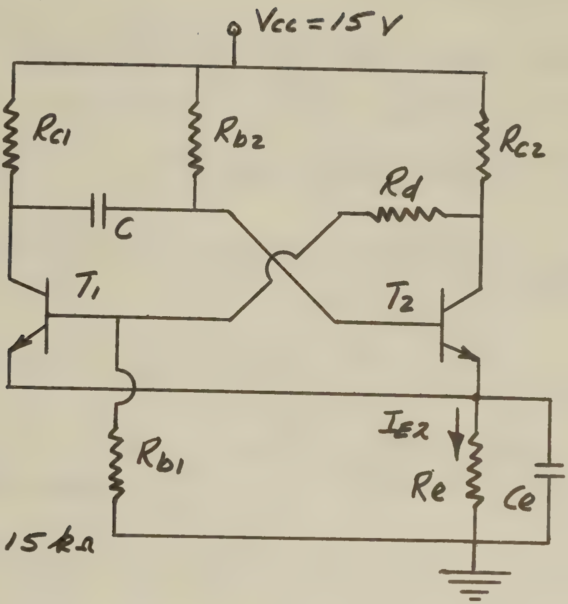
$$V_{BE2} = V_{CC} \left[1 - 2 \exp(-t/\tau) \right]$$

$$\tau = 75 \times 10^3 \times 575 \times 10^{-12}$$
$$= 0.0431 \text{ ms}$$



$$V_{BE2} = 15 \left[1 - 2 \exp(-t/0.043) \right]$$

16.26 (Concl.)



$$R_e = \frac{V_{BB}}{I_{E2}}$$

$$= \frac{6}{5.20} = 1.15\ k\Omega$$

16.27 (a)

Assume T_2 is driven into saturation.

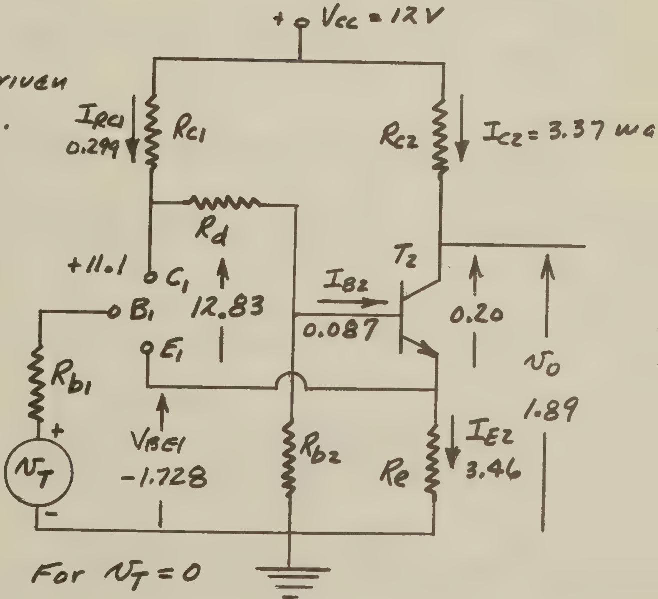
$$I_{C2} \doteq \frac{V_{CC} - V_{CE2}}{R_{C2} + R_E}$$

$$= \frac{12 - 0.20}{3 + 0.5}$$

$$= 3.37\ ma$$

$$I_{BA2} = \frac{3.37}{50}$$

$$= 0.0674\ ma$$



For $v_T = 0$

16.27 (cont.)

$$\text{Actual } I_{B2} = \frac{V_{BB} - V_{BE2} - R_e I_{C2}}{R_{BB} + R_e} \quad (\text{see Fig } 16.16(a))$$

$$R_{BB} = R_{b2} \| (R_{c1} + R_d) = 10 \| (3+30) = 7.67 \text{ k}\Omega$$

$$V_{BB} = \frac{R_{b2} V_{CC}}{R_{c1} + R_d + R_{b2}} = \frac{10 \times 12}{3+30+10} = 2.79 \text{ V}$$

$$I_{B2} = \frac{2.79 - 0.40 - 0.50(3.37)}{7.67 + 0.50} = 0.087 \text{ ma}$$

$$m = \frac{0.087}{0.0674} = 1.29 \quad (\therefore T_2 \text{ is driven into saturation})$$

$$V_{BE1} = v_T - R_{b1} I_{B1} - R_e I_{E2} = 0 - 0 - 0.50(3.37 + 0.087)$$

$$= -1.728 \text{ V}$$

$$I_{RC1} = \frac{12 - 0.40 - 1.73}{3+30} = 0.299 \text{ ma}$$

$$V_{CE1} = 12 - 0.299(3) - (-1.728) = 12.828 \text{ V}$$

$$v_o = 12 - 3.37(3) = 12 - 10.11 = 1.89 \text{ V}$$

(b)

$I_{C1} \doteq I_{RC1}$ (neglecting shunting of $R_d + R_{b2}$)

$$I_{C1} = \frac{V_{CC} - V_{CE1}}{R_{C1} + \frac{(1+h_{FE})}{h_{FE}} R_e} = \frac{12 - 0.20}{3 + \frac{51}{50}(0.50)} = 3.36 \text{ ma}$$

$$I_{B1A} = \frac{3.36}{50} = 0.0672 \text{ ma}$$

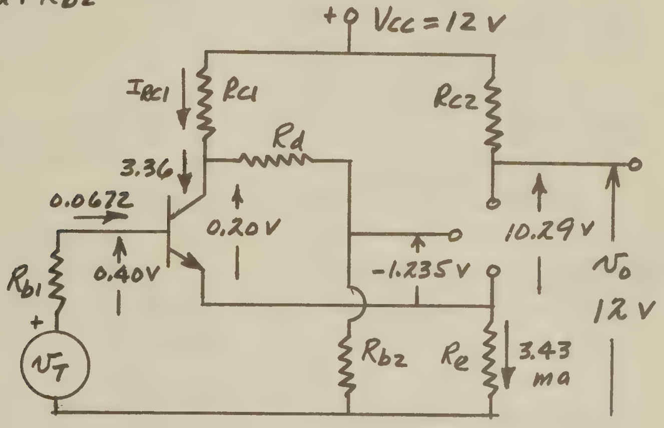
16.27 (concl.)

$$v_T(\min) = R_{b1} I_{B1} + V_{BE1} + R_e(I_{C1} + I_{B1})$$

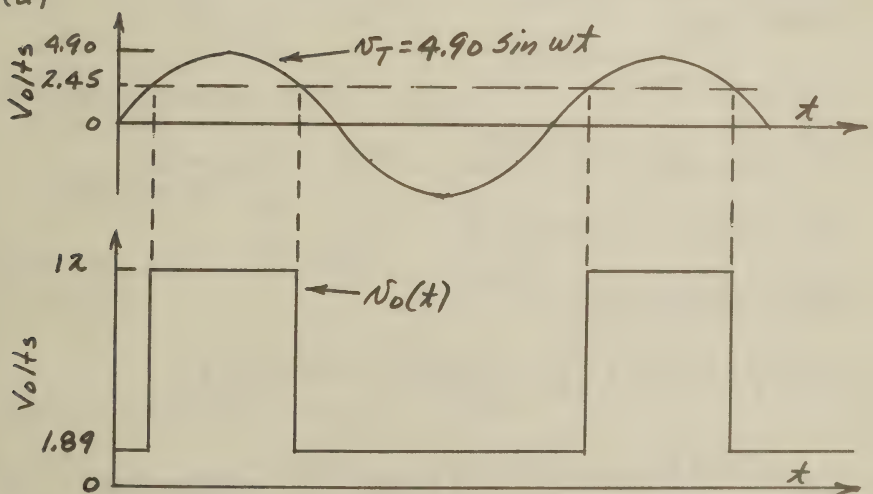
$$= 5(0.0672) + 0.40 + 0.50(3.36 + 0.0672) = 2.45 \text{ V}$$

$$V_{CE2} = V_{CC} - R_E I_{E1} = 12 - 0.5(3.427) = 10.29 \text{ V}$$

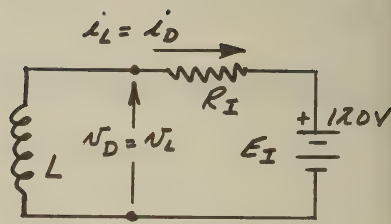
$$V_{BE2} = \frac{(V_{CE1} + R_E I_{E1}) R_{b2}}{R_d + R_{b2}} - R_E I_{E1} = 0.478 - 1.713 = -1.235 \text{ V}$$



(d)



16.28 (a)



$L = 10\,mh$, $R_I = 10\,k\Omega$

$$i_L(t) = -\frac{E_I}{R_I}\left(1 - \epsilon^{-t/\tau_I}\right)$$

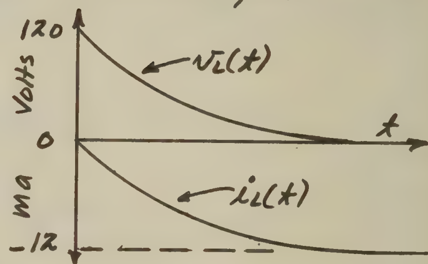
$$= -\frac{120}{10}\left(1 - \epsilon^{-t/1\mu s}\right)$$

$$= -12\left(1 - \epsilon^{-t/1\mu s}\right) \text{ ma}$$

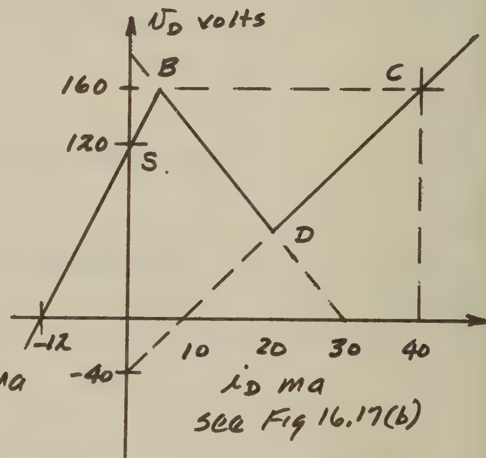
$$\tau_I = \frac{L}{R_I} = \frac{10\times10^{-3}}{10\times10^{3}} = 1\,\mu s$$

$$v_L(t) = E_I\,\epsilon^{-t/\tau_I}$$

$$= 120\,\epsilon^{-t/1\mu s} \text{ V}$$



(b) Since $i_L(0) = 40$ ma, the starting point is at C.



Along the path CD $i_L(t)$ and $v_L(t)$ are given by

$$i_L(t) = 8 + 32\,\epsilon^{-t/2\mu s}$$

$$i_L(D) = 20 = 8 + 32\,\epsilon^{-t/t_{CD}} \text{ ma}$$

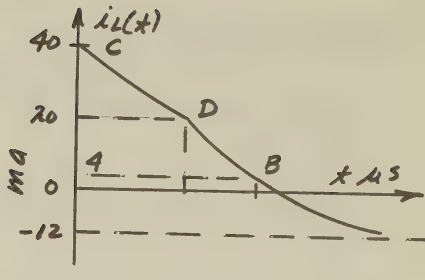
$$t_{CD} = 0.98 \times 2 = 1.96\,\mu s$$

$$v_L(t) = v_D(t) = 160\,\epsilon^{-t/2\mu s} \text{ V}$$

Along path DB: $\tau_{II} = \dfrac{10\times10^{-3}}{-6.25\times10^{3}} = -1.16\,\mu s$

$$i_L(t) = \frac{-185}{-6.25}\left(1 - \epsilon^{t/1.6\mu s}\right) + 20\,\epsilon^{t/1.6\mu s} = 29.6 - 9.6\,\epsilon^{t/1.6\mu s}$$

16.28 (concl.)



$$v_D(t) = 60\,\epsilon^{t/1.6\mu s}$$

$$v_D(B) = 160 = 60\,\epsilon^{t_{DB}/1.6}$$

$$t_{DB} = 0.982 \times 1.6 = 1.57\ \mu s$$

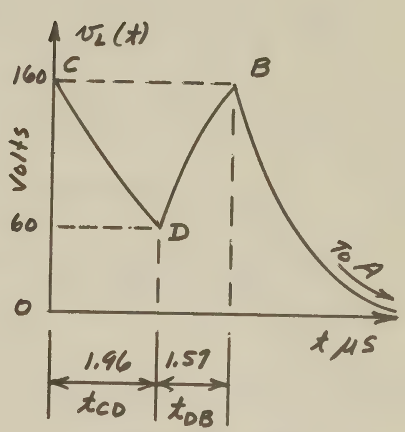
Along path BA:

$$\tau_I = \frac{10\times10^{-3}}{10\times10^{3}} = 1\ \mu s$$

$$i_L(t) = -12 + 16\,\epsilon^{-t/1\mu s}$$

$$v_L(t) = v_D(t) = 160\,\epsilon^{-t/1\mu s}$$

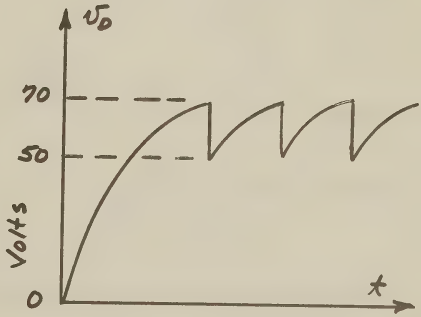
$$v_L(\infty) = 0\ ;\ i_L(\infty) = -12\ ma$$



16.29 Let i_c = capacitor current

Initial charging cycle:

$$i_c(t) = \frac{V}{R}\,\epsilon^{-t/RC}$$



Subsequent charging cycles:

$$i_c(t) = \frac{(V - V_e)\,\epsilon^{-t/RC}}{R}$$

$$v_D\ (\text{charging}) = V - R\,i_c = V - (V - V_e)\,\epsilon^{-t/RC}$$

16.29 (Concl.)

charging period T_c is determined as follows:

$$v_D(T_c) = V_f = V - (V - V_e)\epsilon^{-T_c/RC}$$

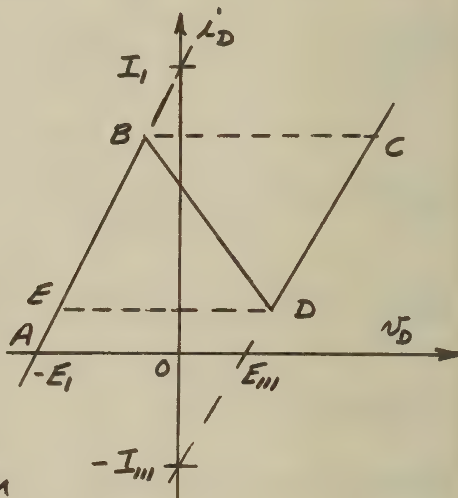
$$T_c = RC \ln\left[\frac{V - V_e}{V - V_f}\right]$$

$$T_c = (1\times 10^6 \times 0.05\times 10^{-6}) \ln\left[\frac{150-50}{150-70}\right]$$

$$= 0.050 \ln 1.25 = 0.050(0.2231) = 0.01115 \text{ s}$$

$$f \doteq \frac{1}{T_c} = \frac{1}{0.01115} = 89.5 \text{ Hz}$$

16.30



Start at point A

$$i_L = i_D = I_1\left[1 - \epsilon^{-t/\tau_1}\right]$$

$$i_L(T_{AB}) = I(B) = I_1\left[1 - \epsilon^{-T_{AB}/\tau_1}\right]$$

$$T_{AB} = \tau_1 \ln\left[\frac{I_1}{I_1 - I(B)}\right]$$

Instantaneous jump from point B to point C.

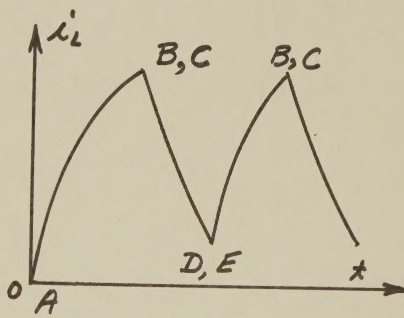
Path C-D:

$$i_L = -I_{III} + [I_{III} + I(B)]\,\epsilon^{-t/\tau_{III}}$$

16.30 (Concl.)

$$i_L(T_{CD}) = I(D) = -I_{III} + [I_{III} + I(B)]\epsilon^{-T_{CD}/\tau_{III}}$$

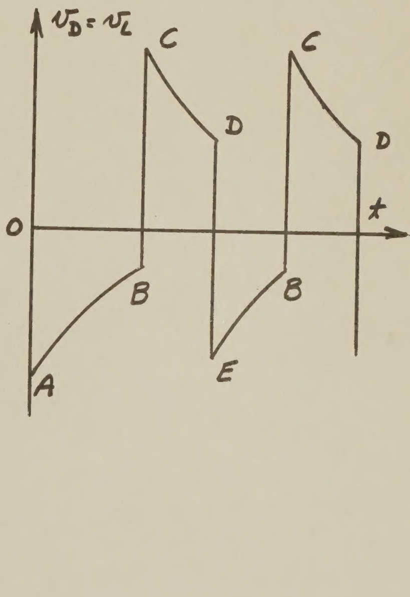
$$T_{CD} = \tau_{III} \ln\left[\frac{I_{III} + I(B)}{I_{III} + I(D)}\right]$$



Instantaneous jump from point D to point E.

$$i_L = I_I - [I_I - I(D)]\epsilon^{-t/\tau_I}$$

$$I(B) = I_I - [I_I - I(D)]\epsilon^{-T_{EB}/\tau_I}$$



$$T_{EB} = \tau_I \ln\left[\frac{I_I - I(D)}{I_I - I(B)}\right]$$

The circuit oscillates at a frequency f_o of

$$f_o = \frac{1}{T_{EB} + T_{CD}}$$

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